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Non-visual Vibro-tactile Navigation of Web Pages on Touch Screen Devices

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Abstract

Sighted persons interpret visually a large amount of visual information and understand complex layouts of rich-media web pages in seconds. First, they navigate a web page by glancing it quickly to get a global overview of the content structure. This process is called skimming. After that, they read the contents of interesting parts in details by following various reading techniques. This process is called scanning. This type of information navigation enables the reader to perceive quickly the document layout and its structural semantics. In addition, it orients quickly the reader attention to interesting parts in a systematic and predictable manner. Unfortunately, persons with visual impairment cannot do this interpretation in the same efficiency. They lose a lot of time to explore the architecture of web pages using computational products specialized for visually impaired persons. These products present sequential interaction styles to navigate the web, one column at a time, one line at a time, one word at a time. They fail to convey the natural ordering of elements in a web page.

Interpreting the spatial layout of a web page is often indispensable to understand its contents. It helps the user in dealing with complex pieces of information by reducing them to a manageable number of units. The layout, and the spatial cues of web pages are very important in enabling many tasks, and in guiding the reader to analyze and to find data items, and in realizing high-level tasks such storing information, quickly finding relevant information, pointing directly to pieces of information present in a web page.

This work presents an approach for non-visual access to web pages. The proposed approach is based on vibro-tactile modality to replace the visual skimming process during navigating web pages displayed on touch-screen mobile devices. It helps the visually impaired persons to get a global overview of the content structure, and to perceive quickly the web page layout.

The approach has been realized by designing a tactile vision sensory substitution system (TVSS). This system converts the visual structures that represent the layout of a web page into vibro-tactile feedbacks. This navigation approach is equivalent to classical visual exploration of a document based on a luminosity vibration. In other words, the visual pieces of information presented on digital screens and obtained by the visual scanning methods are perceived by a manual exploration strategy based on vibro-tactile interaction. This proposed approach could be considered as a new non-visual navigation solution for exploiting the spatial two-dimensional information of web pages interfaces.

A series of experiments has been conducted with visually impaired persons. These experiments confirmed the hypothesis that visually impaired persons can explore graphical geometrical shapes presented on a touch-screen mobile device, and they can perceive their varieties in size, form, spatial relations, and semantic contents through vibro-tactile feedbacks.

Résumé

Les personnes voyantes interprètent visuellement une grande quantité des informations visuelles et comprennent des mises en forme complexes de pages web en quelques secondes. Tout d'abord, ils naviguent une page web rapidement pour obtenir un aperçu global de la structure du contenu. Ce processus est appelé skimming. Après, ils lisent le contenu des parties intéressantes en détails par suivant plusieurs méthodes de lecture. Ce processus est appelé scanning. Ce type de navigation des informations permet au lecteur de percevoir rapidement la mise en forme du document et sa structure. En outre, il oriente rapidement l'attention du lecteur sur les parties intéressantes de manière systématique et prévisible. Malheureusement, les personnes ayant une déficience visuelle ne peuvent pas faire cette interprétation dans la même efficacité. Ils perdent beaucoup de temps pour explorer l'architecture des pages web en utilisant les logiciels informatiques actuels spécialisés pour les personnes ayant une déficience visuelle. Ces logiciels permettent de naviguer séquentiellement les pages web, une colonne à la fois, une ligne à la fois, et un mot à la fois. Ils ne parviennent pas à transmettre l'ordre naturel des éléments sur une page web.

L'interprétation de la disposition spatiale d'une page web est souvent indispensable pour comprendre son contenu, et il permet à l'utilisateur de traiter des informations complexes en les réduisant à un nombre gérable d'unités. La mise en forme, et les indices spatiaux des pages web sont très importants pour permettre nombreuses tâches, et pour guider l'utilisateur à analyser et à trouver des éléments de données, et pour réaliser de tâches plus compliquées tels stocker des informations, trouver rapidement les informations pertinentes, pointant directement toute information présente dans une page web.

Ce travail présente une approche pour un accès non-visuel aux pages web. L'approche proposée est basée sur une modalité vibro-tactile pour remplacer le processus de survol lors de la navigation des pages web affichées sur des appareils mobiles avec écrans tactiles. L'approche aide les personnes ayant une déficience visuelle à obtenir un aperçu global de la structure du contenu, et de percevoir rapidement la mise en forme de la page web.

Notre contribution est la conception d'un système de substitution sensorielle de la vision tactile original. Ce système convertit les structures visuelles qui représentent la mise en forme d'une page web à des vibrations tactiles. Cette approche de navigation reproduit l'équivalent d'une exploration visuelle classique d'un document sur la base d'une vibration de luminosité. Cette approche proposée pourrait être considérée comme une nouvelle solution de navigation non-visuelle pour l'exploitation des informations spatiales des pages web.

Des séries d'expériences ont été menées avec des personnes ayant une déficience visuelle a confirmé l'hypothèse que les personnes ayant une déficience visuelle peuvent explorer des formes géométriques graphiques présentés sur un appareil mobile avec un écran tactile, et ils peuvent percevoir leurs variétés de la taille, la forme, la topologie, les relations spatiales, et les contenus sémantiques en utilisant des vibrations tactiles.

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Introduction

Screen readers are software applications present the contents that are displayed on the screens in a linear interaction way (serially), one item at a time. This presentation method is totally different from the way in which sighted people view visual interfaces. An important accessibility drawback of screen readers is the failure of individuals who are visually-impaired to get quickly an overall sense of a web page in terms of overall semantics, main message, structure, and interaction affordances.

A web page layout is defined as an arrangement of visual elements, so that related items are physically grouped together, in order to guide the user to the information he/she needs. The layouts of web pages have a two-dimensional nature, and this presents more challenges for the uni-dimensional (sequential/serial/linear) interaction styles that are used by screen readers. Nowadays, screen readers provide a top-left to bottom-right navigation approach, and they fail to convey the natural ordering of elements on a web page.

Screen readers present some solutions to navigate the Web, either by transforming a web page into a written braille, or into a vocal output. Some screen readers installed on touch-screen devices transform a web page into a vocal-tactile output. There are many drawbacks for these proposed solutions:

- braille techniques are costly, and only few number of visually impaired persons have learned braille coding;
- majority of current braille solutions are unsuitable for mobile devices, where braille support materials are hardly compatible with mobility issues;
- transforming the information of a web page into a vocal format might not be suitable in public and noisy environments, and listening for a long period to a synthesized speech requires a large amount of focus and increases significantly the user’s cognitive load; and
- failure to transform the 2-D web page layout.

This work focuses on developing and evaluating a system that aims to help the visually impaired persons to perceive quickly the web page layout. The main objective of this work is improving the navigation way for blind people within web pages displayed on touch-screen mobile devices focusing on the tactile modality. To achieve this objective, a tactile vision sensory substitution system (TVSS) has been realized. This TVSS system has been used to execute many experiments with blind and sighted persons in order to answer the following research question "what are the effects of vibro-tactile feedbacks on the ability of people to perceive web pages layouts browsed on touch-screen mobile devices". Despite that the work focuses more on the blind persons, but this question could be posed for the blind and the sighted persons in the modern perspective “design for all”. In other words, the question could be posed as following: "what are the effects of tactile modality on the interpretation and perceiving of web pages layouts".

The system is based on a vibro-tactile solution, cheap, portable, noiseless, efficient in noisy and public environments, and it overcomes the majority of previous mentioned drawbacks. The system works as following:

- first, the system extracts and re-organizes the visual elements of a web page. It groups the adjacent elements together in segments. These segments represent the layout of the web page;
- the system plots then the extracted segments on a touch-screen mobile device;
- finally, it converts the semantic meaning of the extracted visual segments into a vibrating form when interacting with the subject.

The first step aims to extract the web page layout, to reduce and to simplify the density of visual information. Many studies confirmed that extracting semantic information and reformatting web pages can enhance levels of accessibility. Some studies recommended reducing and simplifying the pieces of visual information when converting them to tactile format, in order to accommodate the lower acuity of the touch sense.

Representing the constructed segments on a touch-screen mobile device, and generating the vibration feedbacks are constrained by many rules and criteria. A series of experiments have been conducted to select the best parameters for representing the constructed segments and for generating the vibration feedbacks.

The main contributions of this work are four-fold:

1. modelling an approach that focuses on proving the importance of the vibro-tactile modality to allow better interpretation of the web pages layouts;
2. designing a tactile vision sensory substitution system (TVSS) represented by an electronic circuit and an Android program in order to generate low-frequencies vibrations;
3. designing and evaluating an algorithm for segmenting web pages in order to support the visually impaired persons by a way that aims to enhance their ability for navigating the graphical contents of web pages; and
4. conducting a series of experiments with blind and sighted participants in order to analyze the effects of the suggested approach on web navigation models and tactics of the participants.

Achieving these contributions required dealing with experts of many specializations: electronics, psychology, computer human interaction, and image processing. This thesis describes the state of the art of tactile vision sensory substitution systems, the designed system, and the series of experiments that have been conducted for selecting the best parameters for the designed system.

This thesis consists in three parts. The first one presents the state of the art of works that are targeted to visually impaired persons. It consists in two chapters. The first one presents concepts of the accessibility, the web accessibility, and it views the limitations of current assistive technologies specialized for visually impaired persons. It closes by presenting some concepts about perceiving the web pages layouts, and some principles about vibro-tactile sensation. The second chapter starts by defining the concepts of tactile vision sensory substitution systems. It presents three categories of tactile vision sensory substitution systems, and it closes by presenting many systems targeted to non-visual web navigation.

The second part discusses the main objective of our designed tactile vision sensory substitution system, and some technical details of the proposed solution. It starts first by discussing the objective and the hypothesis of designing the proposed system. Then, the global schema of the system and the methodology to achieve the proposed solution are presented. This part consists in three chapters. The first chapter presents the criteria, conditions, and properties desired to be in the implemented hardware components of the designed system. The second chapter presents the main software components and resources used to construct the system software. The third chapter presents three experiments that have been conducted to select a series of values, and arguments that are fundamental for designing the system.

The third part consists in one chapter. The chapter presents the main experiment that has been conducted with blind and sighted persons to examine their abilities to recognize web pages structures through vibro-tactile feedbacks. The chapter begins by introducing the objectives of the conducted experiment. The designed forms that represent web pages structures are presented. Finally, the protocol of the experiment and the results are presented and discussed.

List of contents

Part 1:

Targeted Users
State of the Art

In August 2014, the world health organization [(1)] estimated that the number of visually impaired persons in the world is 285 million, 39 million of them are blind, and 246 million of them have low vision. The organization defined four levels of visual functions depending on the international classification of diseases, which are: normal vision, moderate visual impairment, severe visual impairment, and blindness [(1)]. Severe and moderate visual impairment cases are considered as "low vision" cases. Low vision and blindness represent all visual impairment cases.

Depending on the international statistical classification of diseases, injuries and causes of death, 10th revision (ICD-10), the low vision case is defined as visual acuity less than 6/18, but equal to or better than 3/60, or a corresponding visual field loss less than 20 degrees in the better eye using best possible correction [Resnikoff et al., 2002]. Blindness is defined as visual acuity less than 3/60, or a corresponding visual field loss less than 10 degrees in the better eye using best possible correction [Resnikoff et al., 2002]. In the literature, the terms congenital (or early) and adventitious (or later) vision loss are used to mention if the vision loss has occurred at birth or later.

In a report about visual impairments released by the world health organization in 2010 [(2)], the organization estimated that:

- more than 65% of visually impaired persons are aged 50 years old or older (this age group comprises about 20% of the world's population);
- about 19 million children below age 14 are visually impaired;
- 7% of blindness cases (about 2.7 million) and 10.4% of low vision cases (about 25.5 million) in the world are in Europe;
- the degree of visual impairment increases after the age of 60 years;
- the degree of visual impairment becomes worse after the age of 80 years;
- 20% of people who are aged between 85 and 89 are classified as being visually impaired [(3)];
- 38% of people who are aged more than 90 are classified as being visually impaired [(3)].

In France, a survey «Disability-Incapacity-Dependency» was carried out by the national institute of statistics in two successive stages between the years 1988 and 2000 [Goillot et al., 2003]. The objective of this survey was to collect and analyze information about disable people in France. The survey has been conducted for a population of 60 million. Some results about visually impaired persons are presented in table 1.1.

Table 1.1 Some statistics about visually impaired persons in France. Survey «Disability-Incapacity-Dependency» between the years 1988 and 2000 [Goillot et al., 2003].

number of totally blind persons	61,000 (about 1 in 1000 of population)
number of severely sight impaired (residual vision limited to making out an outline)	146,000 (about 2.4 in 1,000 of population)
number of less severely sight impaired (persons who are unable to recognize a face at 4 meters away, and unable to read or write)	932,000 (about 15.53 in 1,000 of population)
number of moderately sight impaired (persons who have difficulties in recognizing a face at 4 meters away, and have difficulty reading and writing)	560,000 (about 9.3 in 1,000 of population)

Depending on the previous facts, and knowing that moderately sight impaired cannot normally claim specific assistance, these statistics could be resumed as following: in France, in 2000, number of totally blind persons is 61,000, number of sight impaired persons (severe and less severe) is 1,078,000 [Goillot et al., 2003].

[(1)] http://www.who.int
[(2)] http://www.who.int/blindness/GLOBALDATAFINALforweb.pdf
[(3)] http://www.opc.asso.fr

Statistics of this study show a coherence with the international statistics concerning the age and the gender of visually impaired persons, where the study indicated that the degree of visual impairment is nearly stable before the age of 60, and increases after this age, and becomes worse after the age of 80 [Goillot et al., 2003]. The study presented that there is no significant difference in number of visually impaired persons between men and women (before the age 70, the percentage is nearly equal for men and women; but after the age 70, the number of visually impaired women are more a little than visually impaired men) [Goillot et al., 2003]. 57% of visually impaired persons who use informatics programs are aged less than 60 years [Enquête HID, 2005]. Less than 1% of visually impaired persons in France use machines specialized for producing and dealing with braille texts [Enquête HID, 2005]. The last percentage (< 1%) indicates the need for tools and computational services that do not depend on braille coding.

This part presents the state of the art of works that are targeted to visually impaired persons. It consists in two chapters. The first chapter is entitled "access to spatial information in web pages by visually impaired persons". Chapter one presents concepts of the accessibility, the web accessibility, and it views the limitations of current assistive technologies specialized for visually impaired persons. It closes by presenting some concepts about perceiving the web pages layouts, and some principles about vibro-tactile sensation.

The second chapter is entitled "non-visual access to visual information in numerical documents". Chapter two starts by defining the concepts of tactile vision sensory substitution systems. It presents three categories of tactile vision sensory substitution systems, and it closes by presenting many systems targeted to non-visual web navigating.

Chapter 1:

Access to Spatial Information in Web Pages by Visually Impaired Persons

Résumé : Les personnes malvoyantes dépendent des technologies d'assistance pour accéder au Web et naviguer son contenu. Ces technologies souffrent de nombreuses limitations qui font perdre beaucoup de temps aux personnes malvoyantes lorsqu'elles naviguent sur le Web. Cela motive les chercheurs à soutenir de nouvelles approches non visuelles pour accéder au Web. Ce chapitre a pour objectif de présenter des informations sur les déficiences visuelles et les limitations des technologies d'assistance actuelles pour accéder au Web.

Le chapitre commence par une brève définition des types de déficiences visuelles et des statistiques sur le nombre de personnes ayant une déficience visuelle, suivies par un aperçu de l'accessibilité au Web. Ensuite, le chapitre présente certains types de technologies de l'accessibilité au Web et leurs limites. Le chapitre se termine finalement par la présentation d'idées sur la perception des mises en page Web par les personnes malvoyantes et certains principes sur la sensation vibro-tactile.

1.1 Introduction of Chapter 1

Visually impaired persons depend on assistive technologies to access the Web, and to navigate its content. Assistive technologies suffer many limitations that make visually impaired persons lose a lot of time during navigating the Web. This motivates the researchers for supporting new non-visual methods to access the Web. This chapter aims to view some information about visual impairments, and to present some limitations of current assistive technologies to access the Web.

The chapter begins with a short definition about types of visual impairments, and some statistics about the number of visually impaired persons, followed by an overview of the accessibility, and web accessibility. Then, some types of assistive technologies for visually impaired persons, and their limitations are surveyed. The chapter finally closes by presenting ideas about perceiving the web page layouts by visually impaired persons, and some principles about vibro-tactile sensation.

1.2 Accessibility

Accessibility is designing devices, products, environments, or services, for persons with disabilities or for people with special needs, in order to guarantee a degree of ability to access physical places or virtual environments [Henry et al., 2014]. While accessibility focuses on people with disabilities, it also brings benefits to users with situational limitations, including device limitations and environmental limitations [Henry et al., 2014]. Accessibility is related to concepts as "inclusive design", "universal design", "digital inclusion", and “design for all”. These concepts can be viewed as the processes of creating products, or services usable by persons with the widest possible range of abilities, and operating within the widest possible range of situations [Henry et al., 2014] [Vanderheiden et al., 1998].

While the term accessibility is often used to describe services and facilities to assist people with mobility impairment (like wheelchair, walkers, elevators, adapted automobiles, page-turning devices, adaptive keyboards, adaptive computer mice, pedestrian crossings, etc.), the term covers widely other types of disabilities (such as communication impairment, hearing impairment, mental impairment, learning impairment, perceptual impairment, and visual impairment). Visual impairment accessibility focuses on providing services, technologies, and products to enable more access for visually impaired persons such as walkway contours, hand magnifiers, stand magnifiers, digital talking book players, optical character recognition systems, mouse-over speech synthesizer, braille printers, braille displays, radio reading service, e-texts, and computer accessibility [Chiang et al., 2005] [Vanderheiden et al., 1998].

Computer accessibility for visually impaired persons interests in designing and adapting programs, and software products usable by these persons to overcome significant difficulties in processing the visual cues presented by graphical user interfaces. These software products could be installed on fixed computers, portable computers, mobile phones, or tablets. Rapid advances in information technology make access to computers (and to the Web) essential, and this increases the main role of computer accessibility and web accessibility in everyday life activities [Chiang et al., 2005].

1.3 Web Accessibility

Web accessibility is one of main sub-categories of computer accessibility, regarding the increased importance and expansion of web-based computational programs, and the rapid increase of web-enabled devices such as tablets and mobile phones [Henry et al., 2014]. Web accessibility aims to study and to improve front-end web design towards people with disabilities [Lopes et al., 2010]. In 1997, the director of the international World Wide Web consortium (W3C) [W3C, 2016], Tim Berners-Lee, said: "the power of the Web is in its universality. Access by everyone regardless of disability is an essential aspect." [W3C Accessibility Initiative, 1997]. So, the more the Web is accessible, the more the Web is universal.

Web contains now many types of rich multimedia contents as images (and moving images), animations, frames, tables, videos, widgets (such as buttons, icons, check boxes, and pull-down menus), charts, maps, and more interactive components. All of these components are heavily visually-based. This heavy dependence on visual cues either for viewing or entering data presents a real problem for persons with visual impairment [Kline et al., 1995] [Laux et al., 1996]. There are many other types of rich multimedia contents which make the web pages heavily visually-based. For example, an international survey conducted by WebAIM [(1)] [Webaim, 2016] in January 2009 to analyze the preferences of screen reader users [Webaim_screenreadersurvey, 2009]. 80.1% of participants are totally blind (number of participants is 1121), and 15.8% have low vision, and the others have other types of disabilities (cognitive disability, deafness disability, mobility disability). The following results have been founded:

- the majority of persons participated in the survey confirmed that they avoid flash-based sites;
- the participants enumerated other types of problems in web pages such as images without alternative texts, repetitive links, Java scripts, and AJAX (Asynchronous JavaScript and XML) [Webaim_ screenreadersurvey, 2009];
- this study shows a coherence with other studies which indicate that there is a correlation between complexity (i.e., number of HTML elements - HyperText Mark-Up Language-) and accessibility, the more the web page is complex, the less it is accessible [Lopes et al., 2010].

In order to avoid some web accessibility problems, the consortium W3C [W3C, 2016] in cooperation with individuals and organizations around the world proposed some guidelines known as web content accessibility guidelines (WCAG) [WCAG, 2016]. The objective of these guidelines is "proving a single shared standard for web content accessibility that meets the needs of individuals, organizations, and governments" [WCAG, 2016]. These guidelines explain how to make web content more accessible to persons with disabilities, with mention that web content refers here to the web page information (texts, images, sounds, videos, and other graphical components) or the markups that define the structure and presentation of the information. The latest version of these guidelines is WCAG 2.0, which has 12 guidelines. These guidelines are organized under 4 principles that describe how the web page content should be. The four principles are:

- perceivable (users must be able to perceive the information);
- operable (users must be able to operate the interface);
- understandable (users must be able to understand the information as well as the operation of the user interface); and
- robust (content must be robust enough that it can be interpreted reliably by a wide variety of user agents, including assistive technologies) [WCAG, 2016].

WAI-ARIA [(2)] is another type of set of guidelines [WAI-ARIA, 2016] proposed by the consortium W3C, that defines a way for making the web content and web applications more accessible for people with disabilities, and especially for those who use assistive technologies. These guidelines focus especially on subjects such as "dynamic content" and "advanced user interface controls" developed with AJAX, DHTML (Dynamic HTML), Java scripts, and other related advanced technologies. An example of AJAX problems is changing the content of a web page in response to user actions or time. In this case, the new content may not be available to persons with visual disability who use screen readers. WAI-ARIA provides some technical solutions by adding attributes to identify features for user interaction in a web page. WAI-ARIA describes interaction and navigation techniques to mark regions and common web structures such as menus, banner information, and other types of Web structures. For example, with WAI-ARIA, developers identify regions in a web page, and can enable keyboard users to easily move among these identified regions, rather than moving from one HTML element to another [WAI-ARIA, 2016].

(1) WebAIM or "Web Accessibility In Mind" is an international non-profit organization that works for persons with disabilities [Webaim, 2016].

(2) Web Accessibility Initiative - Accessible Rich Internet Applications [WAI-ARIA, 2016].

Mobile web accessibility is an important branch of web accessibility regarding that mobile devices are nowadays the primary form of accessing the Web [Harper et al., 2014]. Comparing with web accessibility on fixed and portable computers, mobile devices have many limitations and contextual constraints. These limitations and contextual constraints are [Harper et al., 2014]:

- smaller screens,
- restricted visual effects,
- poor lighting conditions,
- usage in noisy environments,
- limited input capabilities. Since traditional interaction models such keyboard or mouse interactions do not exist on mobile devices,
- distributing cognitive resources of the user between multiple tasks.

These limitations and contextual constraints make access the Web more difficult for people with disabilities [Harper et al., 2014]. These limitations and contextual constraints make achieving the basics of web accessibility on mobile devices more difficult than personal computers [Harper et al., 2014] [Trewin et al., 2006].

Despite the importance of creating accessible web pages for variety types of disable persons, and despite the large amount of guidelines for making accessible web sites, many studies indicated that only few pages reach high accessibility levels [Lopes et al., 2010] [Murphy et al., 2008]. A study carried out by the "disability rights commission" in United Kingdom in 2004 has reported that 81% of evaluated web sites failed to meet even the most basic accessibility criteria [Disability Rights Commission, 2004]. Visually impaired people use assistive technologies to access the numerical documents and the Web. Next section describes in details the most common used assistive technologies, and the limitations of each one.

1.4 Assistive Technologies for Visually Impaired People

Current products for visually impaired people such as screen readers depend mainly on speech synthesis or braille solutions. Screen readers identify the textual and graphical elements displayed on a screen, and transfer that information back to the user, via text–to–speech or braille output devices. Screen readers are client supports related to the operating system of the computer [Maurel et al., 2012] such Chromevox (1), Windows-Eyes (2), and Jaws (Job Access With Speech) from the Freedom Scientific (3).

Depending on the survey conducted by WebAIM [Webaim, 2016] in 2009 to analyze the preferences of screen reader users [Webaim_screenreadersurvey, 2009], Jaws is used by 74% of Internet blind users, and Windows-Eyes is used by 23% (used on fixed and portable personal computers). Screen readers present to the users the content viewed on the screen in a linear method (serially), one item at a time, and this is totally different with the way in which sighted people use visual interfaces. Sighted users can get instantaneously an overview of the screen content, comprehending the overall layout of the web pages, the artistic style, and other macro-level aspects of the content. Screen reader users cannot comprehend these macro-level aspects as quickly as sighted users. They depend on a step-wise manner (one item at a time) in order to view the screen content.

(1) http://www.chromevox.com/ [Access 07/01/2016]
(2) http://www.synapseadaptive.com/gw/wineyes.htm [Access 07/01/2016]
(3) http://www.freedomscientific.com/ [Access 07/01/2016]

1.4.1 Braille:

Braille displays are complex and expensive electromechanical devices that connect to a computer and display braille characters. Braille coding is a system of touch reading and writing used by blind persons. Braille coding was invented in 1829 by Louis Braille as a tactile code. It represents tactile patterns of raised dots adapted to the tactile sensitivity of the fingertip [Foulke, 1991]. Each cell in braille tactile coding is composed of a matrix with six dots (three rows, and two columns) that encodes a character or group of characters [Foulke, 1991]. Figure 1.1 represents some examples of the French braille alphabet [Action sociale Handicapés, 2014].

According to the braille production standards (braille characters embossed on papers), the centers of laterally and vertically adjacent dots within a cell are separated by 2.28 mm. The centers of the dots in corresponding positions of laterally adjacent cells are separated by 6.35 mm. The centers of dots in corresponding positions of vertically adjacent cells are separated by 10.16 mm, and the dot diameter is between 1.5 mm and 1.6 mm [Foulke, 1991]. Some studies reported that average braille reading rate (in good conditions of reading) is 124 words per minute (wpm), and this could exceed the speed of sighted readers [Legge et al., 1999] [Lévesque et al., 2007].

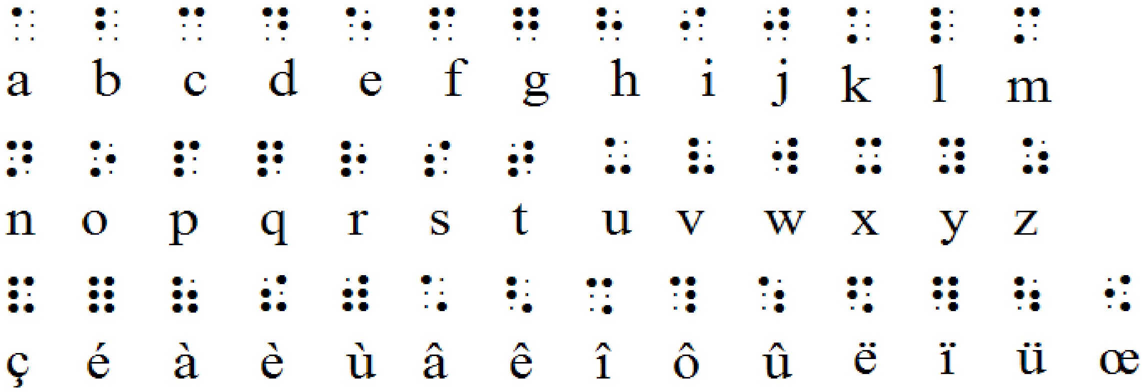

Figure 1.1 Examples of the French braille alphabet [Action sociale Handicapés, 2014].

Refreshable braille displays are electro-mechanical devices used for reading texts that are typically displayed visually on a computer monitor. They are usually connected to the computer by a serial or USB (Universal Serial Bus) cable, and they produce braille output on a line of electromechanical braille cells. Each cell is composed of a matrix of 2 × 4 small plastic or metal round pins that could be moved up and down to display the braille characters. Figure 1.2 views some examples of refreshable braille displays, with different sizes, and different number of braille cells [Walker, 2008].

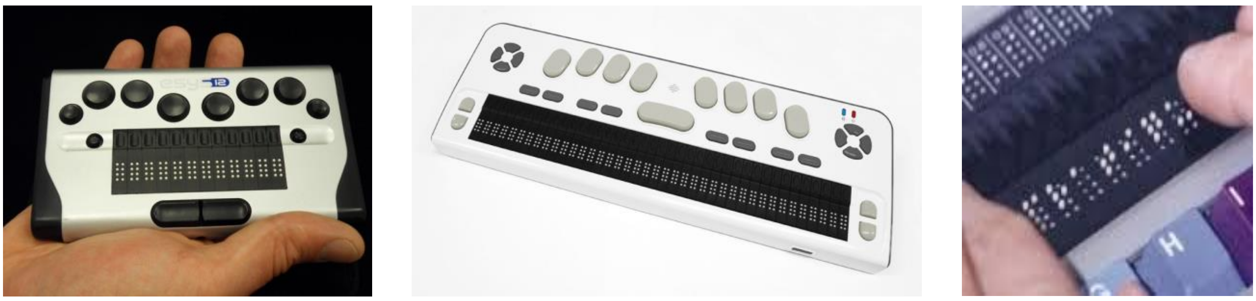

Figure 1.2 Examples of refreshable braille displays [Walker, 2008].

1.4.2 Speech Synthesizers:

Speech synthesis engines convert texts into artificial speech, where the text is analyzed and transformed into phonemes. These phonemes are then processed using signal processing techniques, and connected together to produce artificial synthesized speech. Speech synthesis engines are much cheaper than refreshable braille displays, and they require no knowledge of braille coding. Nowadays, people with visual impairment use increasingly text-to-speech synthesizers rather than braille displays to interact with computers [Stent et al., 2011]. When the visually impaired persons become experienced users of speech synthesizers, they increase multiple times their abilities to understand the synthesized speech [Stent et al., 2011] [Asawka et al., 2003], and they become more successful than sighted persons at understanding synthesized speech [Stent et al., 2011] [Papadopoulos et al., 2010].

In a study published by WebAIM [Webaim, 2016] in November 2014 to analyze the compatibility of screen readers [Screenreader, 2014], it was founded that experienced visually impaired persons often prefer to speed up the reading rate of screen readers to 300 wpm or more. This is more than the inexperienced listener can easily understand [Screenreader, 2014], and once they use to listen to screen readers, they can race through content at speeds that can amaze sighted individuals [Screenreader, 2014]. A study was conducted in 2003 to measure maximum listening speeds of blind persons [Asawka et al., 2003], indicated that blind persons who are experienced users of speech synthesis engines can understand the synthesized speech at least at a speed 500 wpm.

1.4.3 Optical Character Recognizers (OCR):

Some assistive technologies use optical character recognizing techniques (OCR) to provide visually impaired persons with an equal access to printed materials, and produce either braille output or synthesized speech, or the two together. One example of these assistive technologies is Kurzweil reading machine which converts printed characters into synthesized speech [Future Reflections, 1984]. The main drawback of Kurzweil reading machine is that it is not portable and may not be capable of recognizing degraded texts or handwriting [Future Reflections, 1984]. Another example of using OCR techniques for blind persons is Optacon (OPtical to TActile CONverter), which is an electromechanical device enables blind people to read printed materials using a camera to be moved over the printed characters, and a tactile array to output a tactile representation of the scanned characters [Goldish et al., 1974]. The blind person holds the camera by a hand and moves it over a line of printed characters, and the index finger of the another hand rests on a tactile array of 24×6 vibrating pins. As the camera recognizes a character (depending on the optical contrast and on the shape of the character), the image is converted to a shape made by the vibrated pins [Goldish et al., 1974]. After a sufficient training, the blind users can achieve a reading speed of 30 to 60 wpm [Goldish et al., 1974]. Figure 1.3 represents the main elements of Optacon, and how it converts the printed characters [Way et al., 1997].

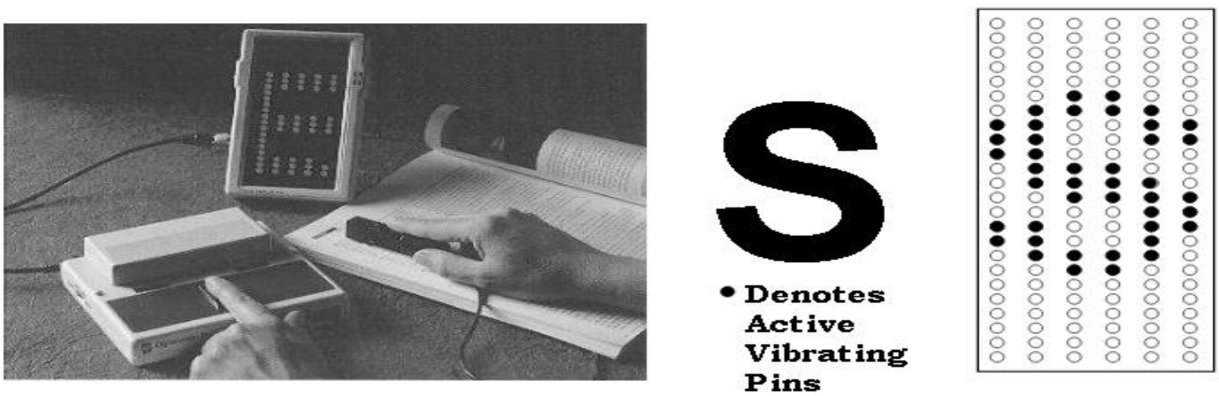

Figure 1.3 Use of Optacon, and demonstrating the capital letter S [Way et al., 1997].

Top-Braille (cf. figure 1.4) is an another example of assistive technologies use optical character recognition techniques to help visually impaired users to read printed texts by transforming them either to braille coding mode or to synthesized speech mode [Top-braille, 2016]. Top-Braille provides also a color recognition technique. The main feature of Top-Braille is its small size that makes it a suitable portable assistive technology.

Figure 1.4 Top-braille devices [Top-braille, 2016].

1.4.4 Screen Readers on Touch-Screen Devices:

Some screen readers can support a tactile feedback when working on touch-screen devices, such as Mobile Accessibility (1), Talkback (2) for Android operating systems, and VoiceOver (3) for iOS (Apple mobile operating systems). Many of these products propose shortcuts for blind users to view a menu of HTML elements in the web page, for example headers, links, and images. Portability, and low cost are the main reasons that make visually impaired persons rely more and more on screen readers installed on touch-screen mobile devices [Kuber et al., 2012]. VoiceOver is currently the most successful solution used by blind people for interacting with touch-screen devices [Maurel et al., 2012]. An important feature of VoiceOver is a virtual drive called “rotor” which is used to access a list of commands and other features. An interesting use of the rotor is for navigating web pages by viewing a list of elements such as headers, links, tables and images, and the user can then select one item and allow navigating among its different occurrences [Maurel et al., 2012]. VoiceOver browses web pages in two modes:

- group mode, in which users navigate between groups of elements such as headers or links;
- document Object Model (DOM) mode, in which the user moves forward or backward through page elements linearly [Stockman et al., 2008].

A survey was conducted by WebAIM [Webaim, 2016] in July 2015 to analyze the preferences of screen readers users (survey version 6). The survey has found the following:

- 69.2% of participated users (2515 participants, 38.7% of them are blind or have low vision) use a screen reader on a mobile phone, mobile handheld device, or tablet [Screenreadersurvey6, 2015];
- 69.6% of participants use Apple platforms (iPhone, iPad, or iPod touch);
- 20.8% of participants use Android platforms, 3.8% of participants use Nokia platforms, and 5.8% use other platforms (Windows Phone, Blackberry, Palm);
- 56.7% of participants use VoiceOver, 17.8% use TalkBack for Android, and 3.0% use Mobile Accessibility for Android [Screenreadersurvey6, 2015].

Few screen readers installed on touch-screen devices support a vibration feedback (devices equipped with more advanced tactile display) [Jayant et al., 2010]. Unfortunately, there is only one vibration pattern which controls the duration of vibration (e.g. no ability to control together the frequency, the amplitude, or the shape of vibration) [Jayant et al., 2010].

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(1) https://play.google.com/store/apps/details?id=es.codefactory.android.app.ma.vocalizerfrfdemo&hl=fr [Access 07/01/2016]
(2) https://play.google.com/store/apps/details?id=com.google.android.marvin.talkback&hl=fr [Access 07/01/2016]
(3) http://www.apple.com/fr/accessibility/ [Access 07/01/2016]

1.5 Non-visual Access to Graphical Information

Access to graphical information (such as charts, figures, graphs, advanced graphical user interfaces, images, and maps) in web pages is a major challenge for persons with visual impairment. Current screen readers cannot transfer to users a meaningful and a real representation about non-text-based information [Giudice et al., 2012]. Screen readers read the alternative texts associated with images, if they are present [Webaim_screenreadersurvey, 2009]. Only 39.6% of images in web pages are assigned with alternative texts [Bigham et al., 2006]. Screen readers consider some graphical components (charts, diagrams, maps, etc.) as complex images, and provide only an alternative textual description (if this description is available by the web page provider) [Screenreadersurvey6, 2015], without providing the visually impaired user by any deep message or knowledge that the sighted user can gain from viewing the same graphical component [Elzer et al., 2008].

Some researchers tried to propose novel approaches for providing visually impaired persons with an access to visual information included in web pages, either by providing automatically additional textual information describing the graphical component, or by transforming the visual content to a tactile output. Some researches tried to mix techniques of text-to-speech synthesis, auditory icons, and tactile feedback to present graphical information [Parente et al., 2003].

On the sound level, some researches focused on a specific type of charts (bar charts) [Elzer et al., 2008], and they tried to provide automatically a textual summary as equivalent as possible to the hypothesized intended message of the graphical component designer. This textual summary is conveyed to the user by a speech synthesizer [Elzer et al., 2008] [Corio et al., 1999] [Demir et al., 2010]. Other researches tried to extract any text found in images (using techniques of image processing and OCR) to supply this text to the user as the image alternative text [Bigham et al., 2006] [Chester et al., 2005]. Some researches tried to convey graphics in an alternative medium by mapping its two-dimensional spatial brightness into an acoustical representation as a function of pixel brightness, pixel position, and time [Meijer et al., 1992]. Figure 1.5 represents an example of transforming an image (8x8 pixels, 3 gray-scales) to an acoustical representation [Meijer et al., 1992].

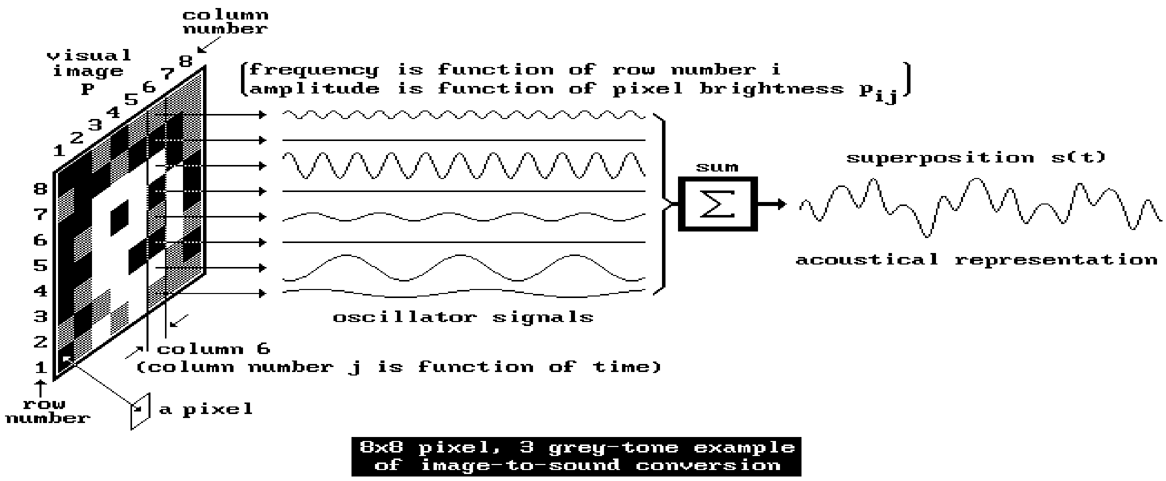


Figure 1.5 Transforming an image to an acoustical representation [Meijer et al., 1992].

On the tactile level, many researches focused on transforming the visual information included in graphical components in web pages to tactile output. Tactile perception is the best way for comprehension of graphical images by visually impaired persons [Dias et al., 2010]. This is due to the high sensitivity of the touch, and its ability to perceive the two dimensional spatial relationships [Dias et al., 2010] [Levesque et al., 2008]. Tactile imaging is defined as converting a visual item, as a picture, into a touchable raised version [Way et al., 1997].

The tactile output could be two-dimensional or three-dimensional representation in a reduced size of the real environment [Hatwell et al., 2003]. Producing tactile graphics poses significant problems and challenges:

- reading tactile graphics implies encoding, processing, and memorizing 2D information, and this could be time-consuming for visually impaired users [Hatwell et al., 2003];
- children have more difficulties in perceiving tactile graphics than adults [Hatwell et al., 2003];
- in case of tactile graphics which represent a real three-dimensional space (such as tactile maps), the congenitally blinds do not have a projective space to understand how the two-dimensional plan on the sheet represents a real three-dimensional space [Hatwell et al., 2003]; and
- congenitally blind persons have difficulties in making spatial inferences [Hatwell et al., 2003].

Tactile graphics are usually displayed on embossed tactile papers. An embosser punches the paper with different sized dots for creating raised shapes [Goncu et al., 2011]. Many guidelines and considerations for creating tactile graphics have been suggested [INSHEA, 2003] [Way et al., 1997]. These considerations take into account the human sensory system, tactual perception, access technologies for tactile graphics production, relevant image processing techniques, and physiological capabilities of the human sensory system to explore via the touch sense. Many researches tried to automate the process of transforming the visual information in graphical components into tactile information such as TACTile Image Creation System (TACTICS) [Way et al., 1997], TeDUB (Technical Drawings Understanding for the Blind) project [Horstmann et al., 2004], a Tactile Web Browser for the Visually Disabled [Rotard et al., 2005], and Tactile Graphics Assistant (TGA) [Ladner et al., 2005]. Figure 1.6 shows an example of rendering an image (contains a diagram and a text) into tactile output by using a tactile graphics display with a resolution of 120x60 pins [Rotard et al., 2005].

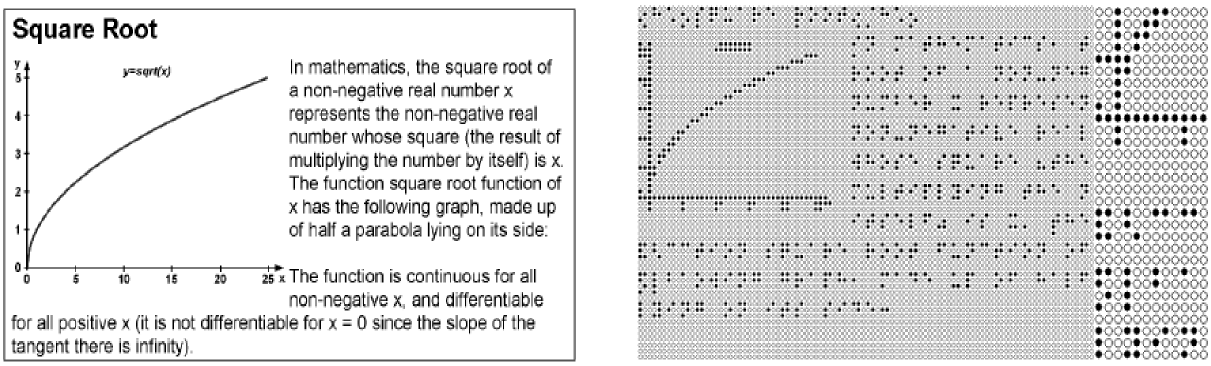


Figure 1.6 Rendering an image into tactile output [Rotard et al., 2005].

1.6 Limitations of Current Assistive Technologies to Navigate the Web

Screen readers present some solutions to navigate the Web, either by transforming a web page into a written braille, or into a vocal output. Some screen readers installed on touch-screen devices transform a web page into a vocal-tactile output. There are some drawbacks for these proposed solutions:

- braille techniques are costly, and only few number of visually impaired persons have learned braille coding. In a survey conducted by WebAIM [Webaim, 2016] in October 2009 to analyze the preferences of screen reader users (survey version 2) [Screenreadersurvey2, 2009], only 29.4% of participated users (665 participants) use braille output with screen readers. In another survey (survey version 4) [screenreadersurvey4, 2010] conducted by WebAIM in May 2012, the percentage has decreased; only 27.7% of participated users (1782 participants) use braille output with screen readers;

- majority of current braille solutions are unsuitable for mobile devices [Maurel et al., 2012], where braille support materials are hardly compatible with mobility issues;
- transforming the information of a web page into a vocal format might not be suitable in public and noisy environments, and listening for a long period to a synthesized speech requires a large amount of focus and increases significantly the user's cognitive load;
- failure to transform the 2-D web page layout. Sighted users look at a web page and quickly realize the organization of the web page, then focusing on the most important content (from their points of view). Visually impaired people cannot navigate the web page in similar way. Current screen readers transfer the web page information into a linear way by strict sequential order, one word at a time, and without any indication for the global web page structure (2D layout). Perceiving the 2D structure greatly improves navigation efficiency and memorizing the information, because it allows high level reading strategies (rapid or cursory reading, finding or locating information, etc.) [Maurel et al., 2003] [Murphy et al., 2008]. Screen reader users must listen (by the synthesized speech) or read (by braille coding) quietly and patiently the description of the page until they come across something that could be interesting to them. They cannot directly select the most important element without attending to the elements that precede it; and
- insufficiency in transforming graphical information in a web page such as charts, diagrams, figures, graphs, maps, advanced graphical user interfaces (GUI components), images, and maps, where access to such graphical information represents a major challenge for visually impaired persons [Giudice et al., 2012].

1.7 Perceiving the Web Page Layout by Visually Impaired Persons

A web page layout is defined as an arrangement of visual elements, so that related items are physically grouped together, in order to guide the user to the information he/she needs [Hornof et al., 2001]. Grouping the related elements helps the user in dealing with complex information by reducing it to a manageable number of units, and to orient quickly his/her attention to interesting parts in a systematic and predictable manner [Hornof et al., 2001].

Interpreting the layout of a document is often indispensable to understand its contents [Francisco-Revilla et al., 2009]. The more the layout is organized and structured, the more improving the speed and quality of visual communication [Hornof et al., 2001]. Many studies confirmed the importance of the structure, the layout, and the spatial cues of web pages in enabling many tasks, and in guiding the reader to analyze and to find data items [Yesilada et al., 2004], and in realizing high-level tasks such storing information, quickly finding relevant information, pointing directly to any information present in a web page, and reading diagonally [Maurel et al., 2012]. Sighted persons navigate the web pages first by scanning it quickly to get a global overview of the content structure (this process is called skimming) [Ahmed et al. 2012]. After that, they read the contents by following various reading paths [Francisco-Revilla et al., 2009] [Ahmed et al. 2012]. This type of scanning enables the reader to perceive quickly the document layout and its structural semantics [Maurel et al., 2012] [Ahmed et al. 2012].

While sighted persons can visually interpret a large amount of visual information and understand complex layouts of rich-media web pages in seconds, persons with visual impairment cannot do this interpretation in the same efficiency, and they lost a lot of time to explore the architecture of web page content using current screen readers [Francisco-Revilla et al., 2009] [Yu et al., 2005]. A recent study concluded that visually impaired persons take more than 10 times longer than sighted persons when they purchase items on the web [Yesilada et al., 2008].

The current trends in designing web sites (interactivity, heavily visually-based components, modular layouts, and dynamic contents) increase the challenges for visually impaired persons to interpret complex layouts of rich-media web pages [Yesilada et al., 2004]. High complexity of current web pages layouts is one of the top reported causes which confuse screen reader users on the Web [Murphy et al., 2008] [Yesilada et al., 2004] [Lazar et al., 2007]. During navigating complex web pages layouts, it is very difficult for the screen reader users to determine their location within the web page [Murphy et al., 2008] [Lazar et al., 2007]. This matches many studies which confirm that conveying additional spatial information could enhance the exploration process of visually impaired Internet users [Murphy et al., 2008] [Lazar et al., 2007] [Yu et al., 2005], and extracting semantic information and reformatting pages can enhance the accessibility levels [Murphy et al., 2008] [Yu et al., 2005].

The layouts of current web pages have a multi-dimensional nature (2 dimensions - spatial representation), and this presents more challenges for the uni-dimensional (sequential/serial/linear) interaction styles that are used by screen readers (uni-dimensional means one column at a time, one line at a time, one word at a time) [Yesilada et al., 2004]. Current screen readers provide a top-left to bottom-right navigation approach, and fail to convey the natural ordering of elements on a web page [Murphy et al., 2008].

The importance of conveying additional spatial information for the visually impaired persons during exploration the web encouraged the researchers to study the nature of the mental model of web page layout for the visually impaired persons. In an empirical investigation to study the difficulties experienced by visually impaired Internet users [Murphy et al., 2008], the authors demonstrated that the mental models of navigated web page layouts formed using screen readers were substantially different to that mental models formed by sighted users. Visually impaired persons described their mental models of web pages structure as a ‘vertical list’ of items headers, links, etc. [Murphy et al., 2008]. The research found that this conceptual vertical-list mental model can reduce the quality of the interaction experience, and it heavily depends on using the short and long-term memory (for example remembering the order of a desired link in a list of links), and this limits their perception of the spatial representation of a web page [Murphy et al., 2008]. In another interesting research, that focused on the differences between sighted and visually impaired users in forming the mental models and initial impressions of web pages [Stockman et al., 2008]. The authors found that the mismatch between the real spatial layout of web pages and the temporal sequential nature of synthesized speech (produced by screen readers) implies increased cognitive difficulties during navigating the Web [Stockman et al., 2008].

1.8 Human-Computer Interaction and Visually Impaired Persons

Human-computer interaction (HCI) is a field of computer science that focuses initially in its researches and practices on cognitive and human factors engineering, and designing technologies where humans interact with computers in novel ways [Card et al., 1983]. This term is referred sometimes as computer–human interaction (CHI), man–machine interaction (MMI), or human–machine interaction (HMI), with confirming that human-computer interaction focuses more on users who are working specifically with computers, rather than other kinds of machines [Card et al., 1983]. The association for Computing Machinery (ACM) defines human-computer interaction as "a discipline concerned with the design, evaluation and implementation of interactive computing systems for human use and with the study of major phenomena surrounding them" [Hewett et al., 1997].

A user interface is defined as the space where interactions between humans and machines occur [Huang, 2009]. Interaction interfaces between humans and computers have been developed very quickly, starting from batch, command-line, and text-based user interfaces; and ending with the current advanced graphical user interfaces (touch, icons, complex web page layouts, and intelligent user interfaces). As already mentioned, graphical user interfaces contain a large amount of visual information, and heavily rely on visual feedback. This huge amount of visual information can cause interaction problems for persons with visual impairments. Taking into account that the mobile touch-screen world is evolving very rapidly with increasingly complex platforms, applications, and web browsers, the previous mentioned interaction problems could be increased when using touch-screen devices, because these devices attempt giving users access to powerful computing services and resources through small visual displays, and limited input techniques due to the need of portability [Dunlop et al., 2002]. The high level visual interaction of graphical interface users on mobile touch-screen devices raises many challenges of accessibility for people with visual impairments, and requires designing more advanced non-visual feedbacks.

Designing suitable non-visual feedbacks (as a respond to certain action) requires understanding well the nature of the action, the intentions beyond the action, and the methodology of perceiving the action and it is feedbacks. This leads to a famous psychological theory that studies the loop between the action and the perception, which is action-perception coupling theory.

1.9 Action-Perception Coupling

Action perception coupling is a psychological theory proposes that persons perceive their environment and events within it in terms of their ability [Witt, 2011] [Proffitt, 2006]. The ecological approach to perception proposed by James J. Gibson [Gibson, 1979] was the first approach talks about this theory [Proffitt, 2006]. According to the action-perception coupling theory, the main objects of perception are affordances [Witt, 2011] [Proffitt, 2006]. Affordances in Gibson's theory mean the possibilities for action [Witt, 2011]. For example, a long way might be a barrier for an aged person; but it might afford walking or running for a sportive person.

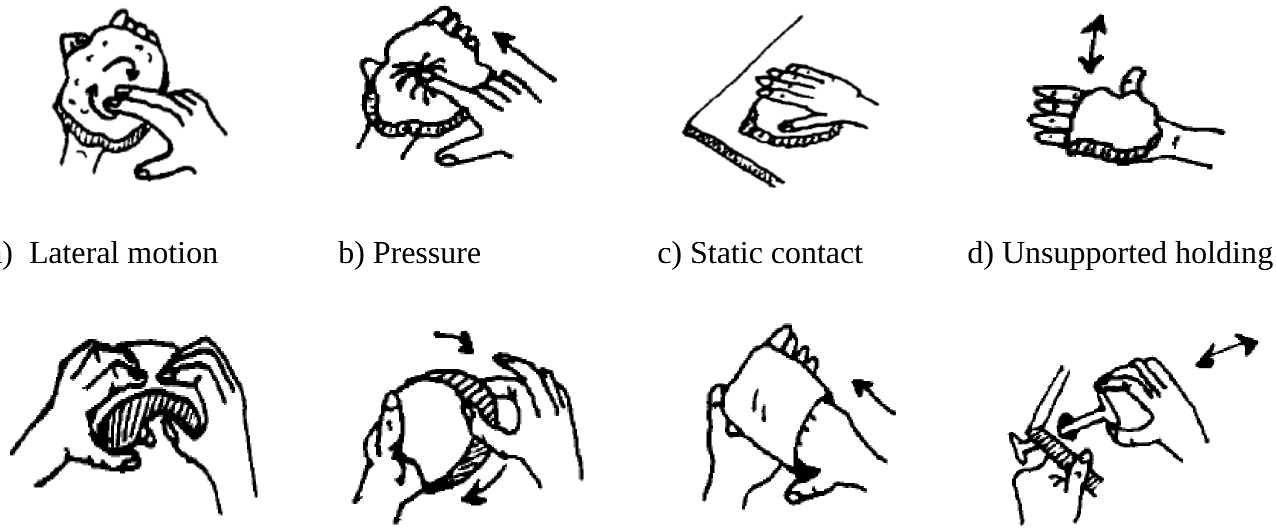
Depending on this theory; similar environments might look different to perceivers with different abilities, or might look different to the same perceiver when his/her abilities change [Witt, 2011]. This approach supposes that persons must perceive in order to move, and they must also move in order to perceive [Gibson, 1979]. This approach is coherent with that of enactive approach. The enactive approach proposes that cognition arises through a dynamic interaction between an acting organism and its environment [Thompson, 2010].

By projecting the concepts of this approach to the non-visual tactile navigation, the action corresponds a non-visual exploration of the touched-screen device. Perception corresponds understanding, recognition, and discrimination the information present on the touched-screen (forms, sizes, spatial relationships, textures, etc.). Hands are the used organs to achieve the actions of the action-perception coupling during the non-visual vibro-tactile navigation. They are also (in some cases) the used organs to receive the generated vibration in case of vibro-tactile navigation. Hands are complex and rich organs for perceiving information [Kalagher et al., 2011]. There are two types of touch by the hands, passive and active [Vega-Bermudez et al., 1991]. Active touch is to explore an object and perceiving its properties in details. For example, when touching an object, the active touch is to hold the object, and to explore its edges, faces, and to estimate its length, width, height, and weight. The passive touch is just the feather-touching of the object without getting detailed characteristics and attributes about it.

In the active touch, hands and arms are always moving and exploring, but in the second type the hands and arms are immobilized [Vega-Bermudez et al., 1991]. The active touch allows the hands to achieve two functions, manipulation of objects, and perception of their properties [Flanagan, 1996]. These two functions (action and perception) are coupled. On the one hand, objects are manipulated in a specific way in order to get information about the objects (action for perception). On the other hand, information perceived by the hand is critical in coordinating manipulatory actions with objects (perception for action) [Flanagan, 1996].

By using the active touch, users apply many exploratory procedures (cf. figure 1.7) to explore the main properties of a touched object (texture, hardness, temperature, weight, volume, global shape, exact shape, part motion) [Lederman et al., 1987] [Lederman et al., 1993] [Lederman et al., 2007].

These exploratory procedures are presented in details in table 1.2.



a) Lateral motion b) Pressure c) Static contact d) Unsupported holding

e) Enclosure f) Contour following g) Function test h) Part motion test

Figure 1.7 Exploratory procedures [Lederman et al., 1987] [Lederman et al., 1993] [Lederman et al., 2007]

Table 1.2 Exploratory procedures and obtained knowledge about touched objects [Lederman et al., 1987] [Lederman et al., 1993] [Lederman et al., 2007].

Exploratory procedure	Knowledge about object	Explanation
lateral motion	Texture	Lateral motion means sideways motions between skin and object surface (rubbing). Interior surfaces are explored, rather than edges.
pressure	Hardness	The pressure is produced by applying normal forces to one part of the object. The another part of the object is stabilized.
static contact	Temperature	The hand passively touches the object.
unsupported holding	Weight	The object is maintained in the hand without any effort to mold the hand to the object.
enclosure	volume/global shape	The hand contacts the envelope of the object.
contour following	volume/exact shape	The hand maintains contact with a contour of the object.
function test	specific function	Executing movements that actually perform certain functions. For example, placing the hand or a finger into a container.
part motion test	part motion	Applying force to a part of the object, while applying counter force to the rest of the object.

Coupling these exploratory procedures and the obtained information indicates that perceiving properties of an object depends on the way by which the object is explored [Vega-Bermudez et al., 1991]. Persons first apply general exploratory procedures to get global information about the touched object. They apply then more specific exploratory procedures to get more details about the touched object, and to get more details about what he/she is looking for [Lederman et al., 1987] [Lederman et al., 1993] [Lederman et al., 2007] [Schwarzer et al., 1999]. Some of these exploratory procedures (such those exploratory procedures for exploration the texture) are existed since the birth [Jouen et al., 2000]. These exploration strategies (from global to more specific) map skimming and scanning strategies by which persons navigate a web page [Francisco-Revilla et al., 2009] [Ahmed et al. 2012].

Vibro-tactile feedbacks could be one of good solutions for supporting non-visual feedbacks [Poupyrev et al., 2004]; as pointed out by many studies. Supporting Vibro-tactile feedbacks might achieve enhancements during performing different tasks using mobile touch-screen devices [Poupyrev et al., 2004]. Non-visual vibro-tactile navigation on touch-screen devices is not a random exploration. It is a type of exploration oriented by the user intention, and it depends basically on perceiving the obtained information during the navigation. This type of navigation (non-visual vibro-tactile navigation) is according with the presented theory action-perception coupling.

The research aims to study the effects of Vibro-tactile feedback in enhancing the interaction of visually impaired persons with touch-screen devices, and more precisely, studying the effects of Vibro-tactile feedbacks to perceive the web page layouts. Next sections present some information about the Vibro-tactile sensation and spatial perception.

1.10 Vibro-tactile Sensation and Spatial Perception

The somatosensory system is a complex sensory system that consists in a number of different sense receptors (also known as somatic senses), including receptors of tactile (touch, vibration, pressure), temperature, pain, and proprioception (sense of equilibrium, or kinesthesia, which means perception the position and the motion of the body parts) [El-Saddik et al., 2011]. These receptors are distributed over all the body, and respond to different types of stimuli, and their delay time ranges from 50 to 500 milliseconds [Renkewitz et al., 2007]. Haptics (a term derived from the Greek word "haptesthai", which means "relating to the touch sense") is the science of applying tactile stimuli (such as textures, pressure, and vibrations), or kinesthetic stimuli (such as weight and impact), or the both sensations together to human–computer enhanced interactions [Renkewitz et al., 2007]. Haptics was first introduced by experimental psychology researchers to refer to the active touch of real objects by humans. In the late period of the twentieth century, this term was redefined to include all the aspects of human–machine touch interaction [El-Saddik et al., 2011]. Haptic communication is defined as means by which humans and machines communicate via touch [El-Saddik et al., 2011].

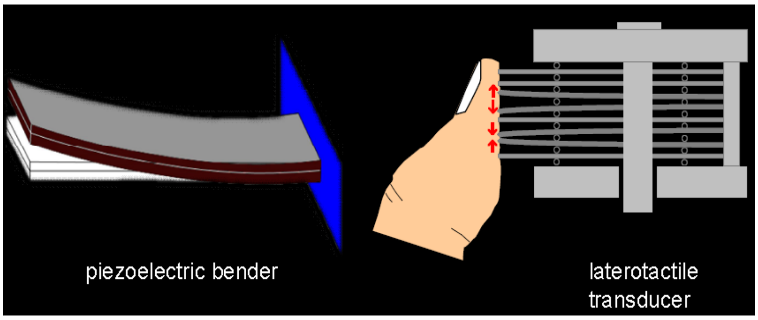
Tactile sensation is related to the cutaneous sense, which is relating to (or involving in) the skin (sensations of pressure, temperature, and pain) [El-Saddik et al., 2011], and human beings possess this sensation from the first weeks of fetal life [Hatwell et al., 2003]. Touch is very sensitive, and it is twenty times faster than vision, and humans are able to differentiate between two stimuli of touch just 5 milliseconds apart [El-Saddik et al., 2011]. When converting visual graphic information into tactile forms, many requirements should be taken into account to accommodate the lower acuity of the touch sense, such as simplification of contents and reduction of the information density [Levesque et al., 2008].

Vibro-tactile sensation is related to vibrating stimuli, and related to perception of vibrations through touch. Despite it is difficult to select definitive ranges about the perceptual capabilities of the tactile receptors (their responses are nonlinear, and measured sensitivity varies greatly with stimulus size, shape, and duration), researchers make generalizations to define perceptual thresholds of the tactile receptors [Kontarinis et al., 1995]. Tactile receptors are highly sensitive to vibration, where the peak sensitivity is around 250 Hz [El-Saddik et al., 2011], and the most perceptive range is between 250 Hz and 300 Hz [Kontarinis et al., 1995], and the tactile perception of vibration extends from 0.04 Hz to 500 Hz [Bolanowski et al., 1988], and frequencies greater than 500 Hz are felt more as textures, not as vibration [Bolanowski et al., 1988].

In 2003, detailed guidelines, recommendations, and considerations for creating tactile graphics on embossed papers have been proposed in a study conducted by the higher national institute of training and research for the education of disabled young people and adapted teaching (INSHEA: Institut national supérieur de formation et de recherche pour l'éducation des jeunes handicapés et les enseignements adaptés) [INSHEA, 2003]. For example, depending on these recommendations, the distance between two elements (lines or dots) should be between 0.5 mm and 4mm [INSHEA, 2003].

A series of interesting tactile experiments were conducted to study the ability of visually impaired persons to identify the basic elements of tactile graphics (shapes, textures, orientations) using a 2D refreshable laterotactile graphics display system (the system uses 8x8 piezoelectric motors), laterotactile means using the technique of lateral skin deformation. Figure 1.8 presents an example of a lateral skin transducer [Levesque et al., 2008], and an example for illustrating the difference between lateral deformation and the normal indentation [Hayward et al., 2000]. Despite this study has not been achieved on touch-screen devices, but the closeness between the achieved experiments and those achieved during the PhD encourages to detail here all the obtained results.

In order to extract a specification of appropriate tactile rendering patterns, the study used four methods of rendering (dotted outlines, vibrating patterns - controlling the deflection of each actuator generates a vibratory sensation -, virtual gratings, and combinations of the previous three rendering methods) as illustrated in figure 1.9.



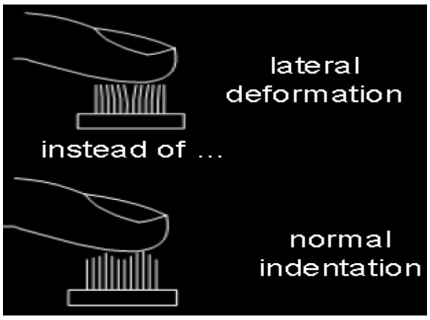
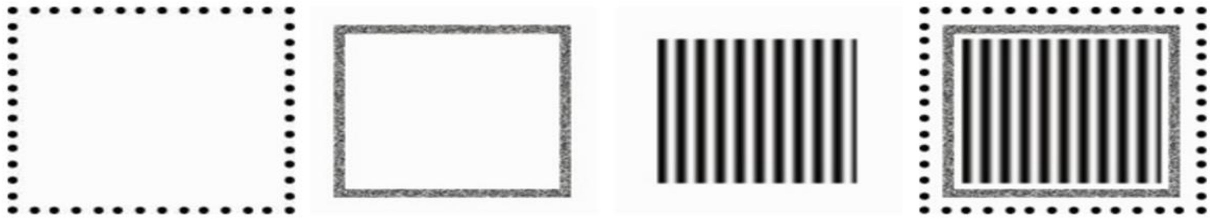


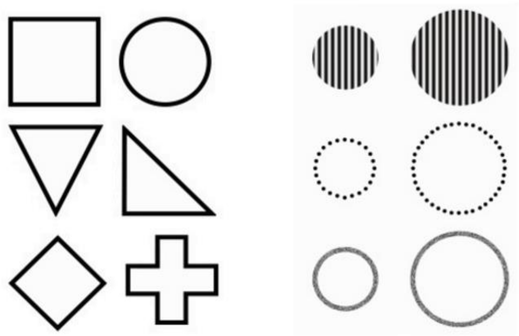
Figure 1.8 (a) A lateral skin transducer [Levesque et al., 2008], (b) The difference between lateral deformation and the normal indentation [Hayward et al., 2000].



(a) (b) (c) (d)

Figure 1.9 Visual illustration of squares rendered with (a) dots, (b) vibration (controlling the deflection of each actuator), (c) gratings, and (d) a combination of all three [Levesque et al., 2008].

These methods of rendering have been used to identify six shapes with 2 different sizes for each one. The shapes are presented in figure 1.10 (a). Figure 1.10 (b) represents applying these methods on circles with two sizes. The average performance was 85.2% of accuracy for vibrating shapes, 78.0% of accuracy for dotted shapes, 76% of accuracy for combination patterns, and 64.8% of accuracy for grating-textured shapes. These results indicate that using vibrating patterns is more efficient than other methods [Levesque et al., 2008].



(a) (b)

Figure 1.10 Shape identification experiment: (a) six shapes and (b) example of the six variations of a circle [Levesque et al., 2008].

The second experiment was conducted to determine the spatial width necessary to distinguish gratings, with considering that the distance between two gratings is 1 cm. In this experiment, the spatial width length of the gratings varied between 1.0 and 6.0 mm with 0.5 mm increments. Figure 1.11 views two examples of series of this experiment with different widths [Levesque et al., 2008]. Subjects were asked to identify the grating with highest spatial frequency between pairs of grating. As a result, the success rate gradually increases from 74.4% of correctness matching at width 0.5 mm to near perfection at and above width 3.0 mm.

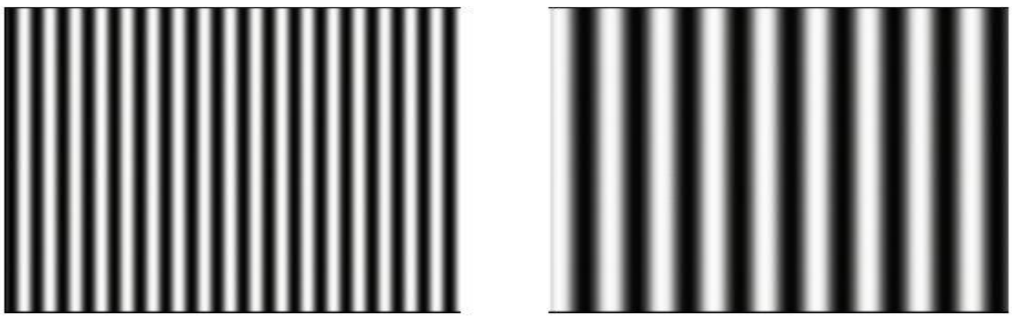
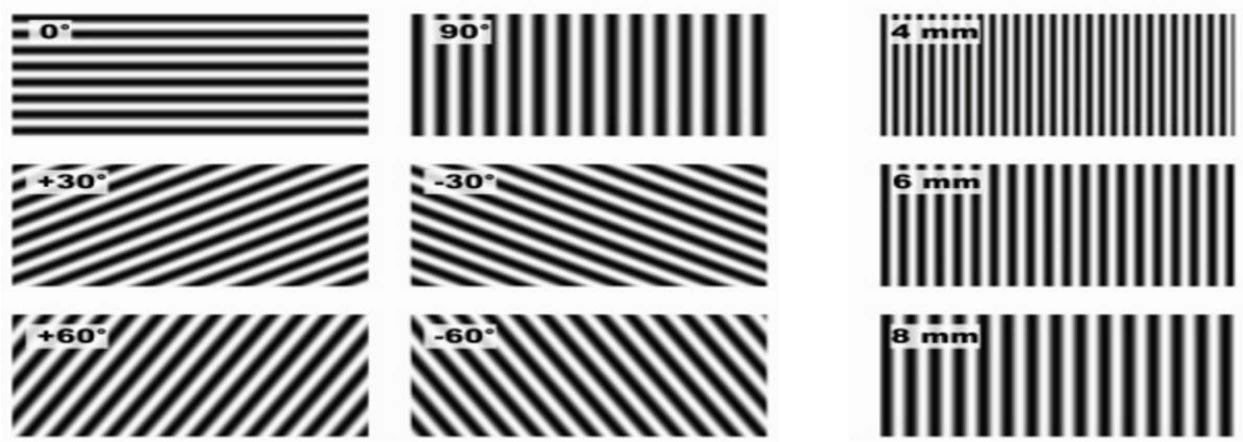


Figure 1.11 Two examples of grating spatial frequency comparison experiment, with gratings widths of 3 mm and 6 mm [Levesque et al., 2008].

Two experiments of grating orientation have been conducted to evaluate the ability of visually impaired persons to perceive the orientation of virtual gratings, and to evaluate the effect of spatial frequency on orientation judgments. In the first experiment of orientation, six orientations (0°, +30°, +60°, +90°, -30°, -60°) at three different spatial wavelengths (4 mm, 6 mm and 8 mm) have been evaluated. Figure 1.12 presents the six orientations with the three different spatial wavelengths [Levesque et al., 2008]. In the second grating orientation experiment, four orientations (0°, 90°, +45°, -45°) at one spatial width length 6 mm (the best width length found in the first experiment) have been evaluated. The mission of subjects was to identify the grating orientation displayed by the system. For the first grating orientation experiment, the results were as following: the correctness average percentage was 46.1%, horizontal (0°) and vertical (90°) grating orientations were identified more easily (76.0% of correctness for horizontal orientation, and 60.6% of correctness for vertical orientation). The results of average correctness for grating wavelength 4 mm, 6 mm and 8 mm were correctly identified 41.8% (4 mm), 50.7% (6 mm) and 45.7% (8 mm) respectively. So, depending on this experiment, the best orientations of gratings are horizontal and vertical, and the best width length of gratings is 6 mm.

Concerning the results of the second experiment, horizontal (0°) and vertical (90°) were identified correctly 88%, and the average correctness for the grating orientation +45° was 87%, and 85% for -45°.



(a) Grating orientations (b) Spatial wavelengths

Figure 1.12 (a) Grating orientations (0°, +30°, +60°, +90°, -30°, -60°), (b) three different spatial wavelengths with orientation +90° [Levesque et al., 2008].

The braille authority of North America published in 2010 guidelines and standards for generating tactile graphics to be produced on micro-capsule braille papers [Brailleauthority, 2010]. In these guidelines, many groups of textures, line styles, point symbols, and arrow symbols have been suggested. Figures 1.13, 1.14, and 1.15 present some examples of proposed textures, lines, and arrows symbols respectively [Brailleauthority, 2010].

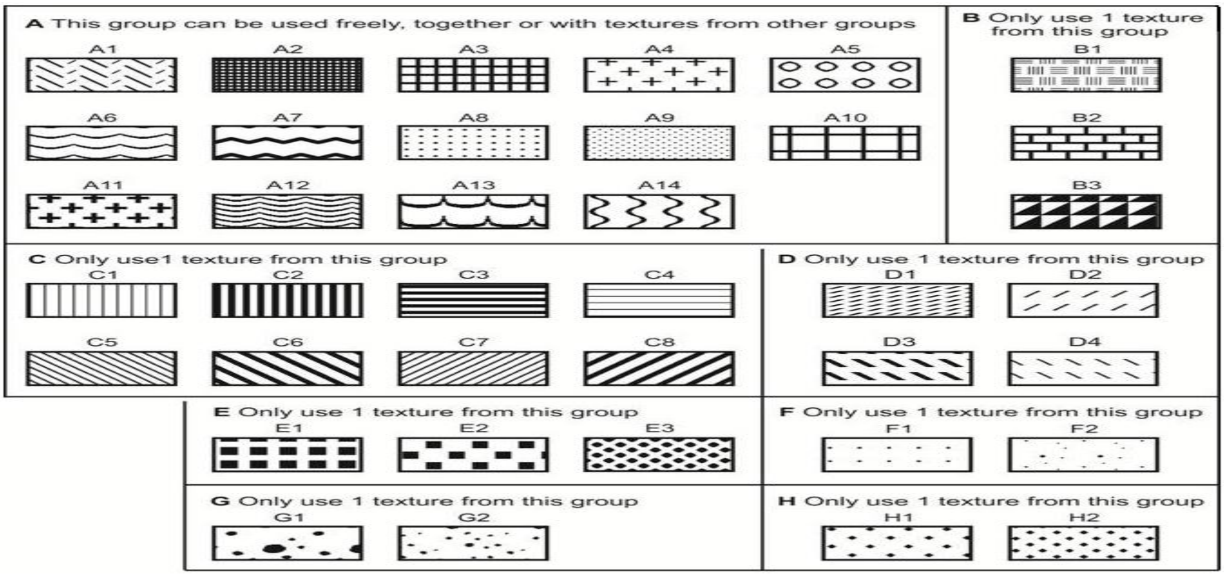


Figure 1.13 Groups of proposed textures for generating tactile graphics [Brailleauthority, 2010].

Figure 1.14 Set of proposed lines for generating tactile graphics [Brailleauthority, 2010].

These guidelines indicated that the distance between lines, points, and arrows should be greater than 3.175 mm. Concerning the dashed lines, the length of each dash should be from 6.35 mm to 9.525 mm, and the space between two dashes should be approximately half the length of the dash. The length of non-dashed lines must be at minimum 1.27 cm. The minimum diameter of a point symbol must be at least 6.35 mm [Brailleauthority, 2010].

Figure 1.15 Set of proposed arrows for generating tactile graphics [Brailleauthority, 2010].

As touch-screen devices have come widely into use, and regarding the importance of graphical and spatial information in web pages, many researches have been conducted to study the ability of visually impaired persons to build an internal spatial representation (mental representation) equivalent to the graphical and spatial information viewed on touch-screen devices [Goncu et al., 2011]. Many types of tactile feedbacks could be provided to the users, such as audio-tactile feedback (using speech accompanied by the tactile sensation), Vibro-tactile feedback (using vibration accompanied by the tactile sensation), sonification (using non-speech sounds accompanied by the tactile sensation), etc [Goncu et al., 2011].

Designing non-visual Vibro-tactile interfaces on touch-screen devices requires defining the perceptual capabilities of tactile receptors for perceiving spatial information (sizes, shapes, distances, directions, positions, relations, etc.) represented on touch-screen devices. An interesting study that was conducted for learning non-visual graphical information using a touch-based vibro-audio interface [Palani et al., 2014], found that the optimal line width for perceiving Vibro-tactile lines on touch-screen devices is 8.89 mm, and this value is the best to be used as the minimum inter-line distance (minimum distance between two lines) [Palani et al., 2014]. Another study indicated that it is very difficult for visually impaired persons (during their interaction with touch-screen devices) to distinguish 2D objects with width or height smaller than 5mm [Goncu et al., 2011].

1.11 Conclusion of Chapter 1:

Perceiving the layouts, the structures, and the spatial cues of web pages is very important to enable visually impaired persons navigating web pages. Researchers try to invent new methods to stimulate unimpaired senses of visually impaired persons to enable them perceiving the spatial information in web pages. In chapter one, many aspects concerning the visual impairments have been discussed. The accessibility issues, and especially web accessibility, have been defined and discussed. The limitations of current assistive technologies for visually impaired persons have been presented, in addition to a short discussion about the Vibro-tactile sensation.

The huge number of visually impaired persons in the world (285 million in 2014) requires supporting news technologies to overcome the current limitations of assistive technologies. Braille displays are expensive and complex devices, and few numbers of visually impaired persons know braille coding. Speech synthesizers are cheaper than braille displays, but they support the information in a linear way (serially). This linear way in presenting the information is not suitable for heavily visually-based interfaces, such web pages interfaces, and does not support any information about the two dimensional structure of the documents. The new technologies in presenting and updating the presented information in web pages require more advanced technologies to overcome such these limitations. Next chapter presents the state of the art of systems and researches that present solutions and approaches for supporting non-visual access to visual information in numerical documents.

Chapter 2:
Non-visual Access to Visual Information in Numerical Documents

Résumé : Les systèmes de substitution visuo-tactile (TVSS) localisent l'information visuelle sur la surface de la peau. La conception de ces systèmes nécessite d'étudier et de définir les capacités perceptives des récepteurs tactiles pour percevoir des signaux tactiles. Ce chapitre présente quelques détails des systèmes qui présentent des solutions et des approches pour soutenir l'accès non visuel à l'information visuelle dans les documents numériques.

Le chapitre commence par une définition des systèmes de substitution sensorielle, suivie par une définition des systèmes de substitution sensorielle visuo-tactile. Trois catégories de systèmes de substitution sensorielle visuo-tactile sont présentées. Le chapitre se termine finalement par la présentation de nombreux systèmes qui fournissent la navigation non-visuelle sur le Web.

1.1 Introduction of Chapter 2

Tactile vision substitution systems (TVSS) map visual information onto the surface of the skin. Designing these systems requires studying and defining the perceptual capabilities of tactile receptors to perceive tactile signals. This chapter introduces some details in a wide range of systems that present solutions and approaches for supporting non-visual access to visual information in numerical documents. The chapter begins with a definition of the sensory substitution systems, followed by a short definition of tactile vision sensory substitution systems. Three categories of tactile vision sensory substitution systems are presented, braille-oriented, vibration-oriented, and spatial-oriented tactile vision substitution systems. The chapter finally closes by presenting many systems that provide non-visual web navigating.

2.2 Sensory Substitution Systems

A sensory substitution is defined as using one human sense to receive information normally received by another sense [Kaczmarek, 2000]. A sensory substitution system transforms stimuli characteristics of one sensory form (such as vision) into stimuli of another sensory form (such as touch) [Hatwell et al., 2003]. For example, braille coding and speech synthesizers are systems that substitute touch and hearing, respectively, for visual information [Kaczmarek, 2000]. There are many types of sensory substitutions, such as auditory vision substitution, visual auditory substitution, tactile auditory substitution, and tactile vision substitution [Kaczmarek, 2000]. In this chapter, a more attention will be given to vision substitution systems, and especially tactile vision substitution systems.

Sensory substitution systems were introduced officially in 1969 by [Bach-y-Rita et al., 1969]. The objective was to use one sensory modality (tactile) to gain environmental information to be used by another sensory modality (vision in this case) [Humphrey, 1999] [Bach-y-Rita et al., 1969]. The authors depend on the following idea: in the intact visual system, the optical image goes only to the retina. In the retina, the image is turned into electrical impulses in the optic nerve; the received impulses are then interpreted in the brain to recreate the image [Bach-y-Rita et al., 1969] [Bach-y-Rita, 1972]. Perceiving an image does not depend only on analyzing the received impulses in the brain; but it depends –in addition to that- on the memory, the learning, the contextual interpreting of the received information, and other features [Bach-y-Rita et al., 1996].

A bandwidth of a sense is the capacity of a sense to receive and perceive information [Way et al., 1997]. Vision is the highest bandwidth sense (10^6 bits/second), followed by hearing (10^4 bits/second) and touch (10^2 bits/second) [Way et al., 1997]. This implies the following:

- visual information cannot be mapped directly to auditory or tactile forms;
- density of visual information must be reduced when it is substituted for another sensation form, with preserving the meaning of the original visual information.

An example of reducing the intensity is transforming visual graphical information into tactile representation. This transforming requires simplifying the contents, and reduction the information density to take into account the lower acuity of the touch sense comparing to the visual sense [Levesque et al., 2008].

Designing a successful sensory substitution system should meet many requirements and considerations to be efficient and usable. Following requirements and arguments should be taken into account [Meijer et al., 1992] [Levesque et al., 2008]:

- cheapness,
- portability,
- low-power,
- limited capabilities of human users,
- offering an easy-to-learn high resolution mapping,

- operating in real-time,
- ergonomic aspects,
- simplicity in running the system,
- typical characteristics of the user environment, and
- knowledge about the sensory forms from which and into which the information should be transformed. For example, in case of the tactile sensory form, it is very important that the designer makes attention to the difference in sensitivity between the skin areas. Unlike the ears and the eyes, the haptic stimuli receptors are not situated in one part in the human body, but they are distributed along whole the body. A study was conducted in 1950 showed that the hands, the tongue, and the lips are the most sensitive parts in the human body [Penfield et al., 1950]. Figure 2.1 shows the sensory homunculus diagram, where the size of each body part represents how much its skin is sensitive to touch stimuli [Penfield et al., 1950].

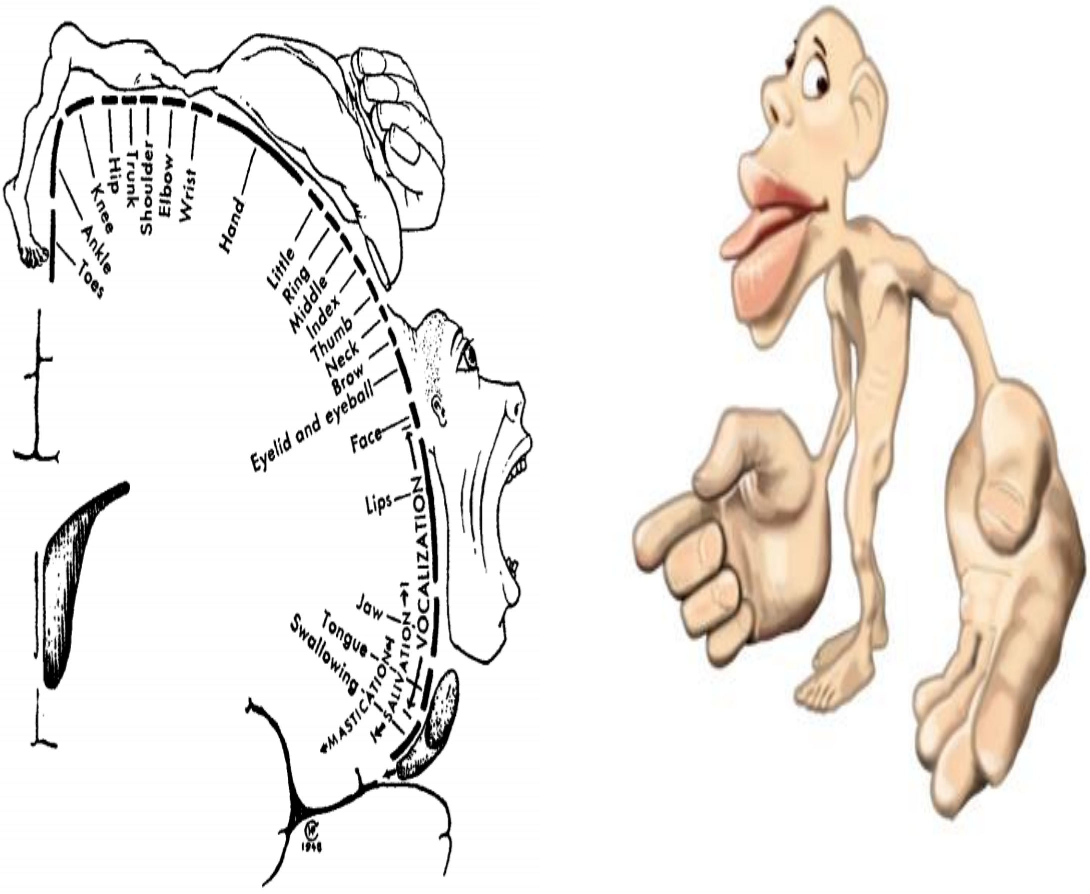


Figure 2.1 Sensory homunculus diagram [Penfield et al., 1950].

2.3 Tactile Vision Substitution Systems

A tactile vision substitution system (TVSS) transforms the visual information into tactile stimulation, in order to provide a greater variety of environmental information [Warren et al., 1984]. In following sections, many examples of tactile vision substitution systems are presented. The presented systems are classified into three categories:

- braille-oriented tactile vision substitution systems that focus on transforming the visual information into braille coding;
- vibration-oriented tactile vision substitution systems which transform the visual information into vibro-tactile format; and

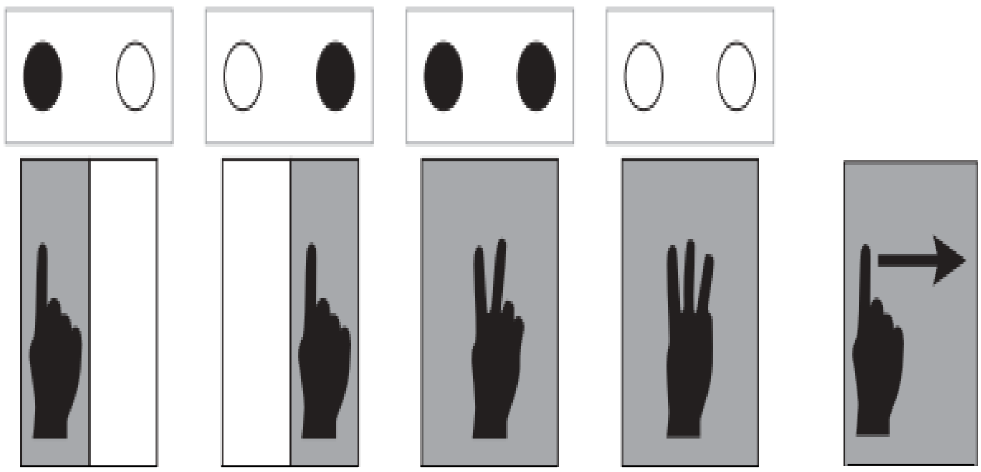
- spatial-oriented tactile vision substitution systems that focus on transforming the spatial information into tactile format.

This taxonomy (classification to 3 categories) has been chosen to facilitate grouping the presented approaches, and to group similar or close approaches together; taking into account that some systems could be classified in more than one category. For example, systems that transform spatial visual information into vibro-tactile format could be included in vibration-oriented tactile vision substitution systems, and might be included in spatial-oriented tactile vision substitution systems.

2.3.1 Braille-Coding Oriented Tactile Vision Substitution Systems

Many researches have been conducted to propose a replacement of current refreshable braille displays, regarding their high costs and immobility. Some researchers have proposed braille-based approaches for visually impaired persons to allow them entering texts on mobile touch-screen devices, either by gestures, or by direct pointing. The programs that allow entering Braille texts are useful for making visually impaired persons more familiar with Braille coding. This section presents first the state of the art for applications specialized in entering Braille texts. The start of the art for applications oriented to replace refreshable braille displays is then presented.

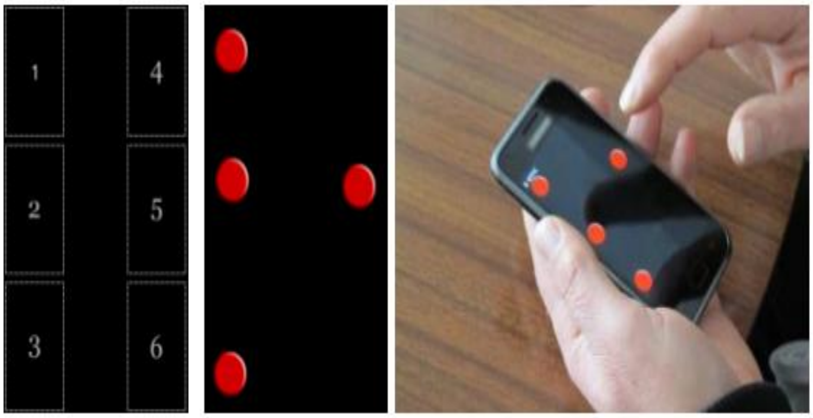
TypeInBraille is a braille-based typing application for touch-screen devices [Mascetti et al., 2011]. The proposed approach enables entering a braille character by inserting the three rows of each braille character cell from the top to the bottom. In order to enter a row, the touch-screen is divided into equal two rectangles (left and right) and four gestures are defined, as presented in figure 2.2 (a, b, c, and d) [Mascetti et al., 2011]. A gesture (from left to right) is specialized to indicate the end of entering a character. This gesture is presented in figure 2.2 (e) [Mascetti et al., 2011].



(a) (b) (c) (d) (e)

Figure 2.2 Gestures for entering a row (tow dots) in a braille cell, (a), (b), (c), and (d). (e) a gesture to end entering a character [Mascetti et al., 2011].

BrailleType is an example of braille-based approach for entering braille characters [Oliveira et al., 2011]. BrailleType is considered as an adaptation of the traditional braille coding for the touch-screen devices. In this approach, a braille cell is presented on the touch-screen by viewing six large rectangles; each rectangle represents a dot in a braille cell, as presented in figure 2.3. The rectangles are arranged according to the known and expected traditional arrangement of dots in braille cells. Depending on this arrangement, the positions of dots become spatially easy to be found. The system supports an audio feedback as a confirmation message after each single touch [Oliveira et al., 2011]. The average speed of text-entry task using BrailleType has been estimated to 1.45 wpm (words per minutes) in an experiment of short training period for 15 blind participants, comparing with 2.11 wpm using VoiceOver [Apple Accessibility, 2016].



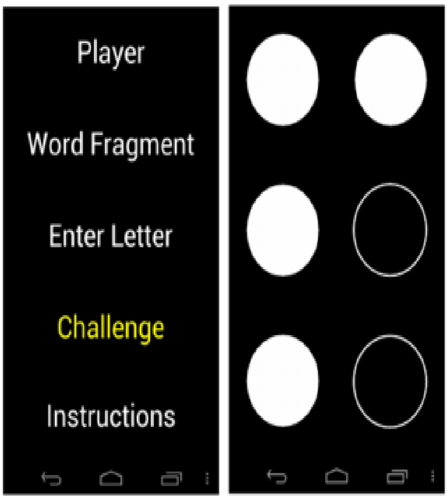
(a) (b) (c)

Figure 2.3 BrailleType prototype, (a) BrailleType main screen, (b) representation of letter 'r' in BrailleType, (c) an example of using BrailleType [Oliveira et al., 2011].

Some braille-based approaches support a vibro-tactile feedback on mobile touch-screen devices. The application V-braille divides the mobile screen into six regions to simulate the six dots in a single braille cell [Jayant et al., 2010]. V-braille supports a vibro-tactile feedback when the user touches any location inside a cell that represents a raised dot [Jayant et al., 2010]. The preliminary evaluation of V-Braille was conducted with 9 deaf-blind braille readers. The results showed 90% of accuracy rate to read V-Braille characters, and 15.4 seconds as time average to read a V-braille character [Jayant et al., 2010].

Body-Braille is another braille-based approach that provides a vibro-tactile feedback as a way to communicate with deaf-blind people. In this approach, six micro vibration motors are used to present a braille character. The micro vibration motors could be attached to any part of the whole human body [Ohtsuka et al., 2008]. The evaluation experiments to measure the speed of reading indicated that the average reading time for one braille character was 0.95 seconds, with 80% of accuracy rate. Many parts of the body were tested to evaluate Body-Braille; results showed that the most preferable parts of the body are the arms [Ohtsuka et al., 2008].

VBGhost is an accessible, educational, smart-phone game for visually impaired persons [Milne et al., 2013]. VBGhost is based on the word game Ghost, in which players add letters to complete a suggested word fragment. VBGhost uses audio and haptic feedback. Players enter letters by using braille dot patterns on a touch-screen interface, as presented in figure 2.4. Players can raise or lower dots to create braille characters using taps and audio feedback. When a “raised” dot is touched on the screen, the phone vibrates [Milne et al., 2013].



(a) (b)

Figure 2.4 Interfaces of VBGhost, a) an audio menu of VBGhost, and b) representing the letter "p" in Braille coding [Milne et al., 2013].

A vibro-tactile braille-based approach has been proposed by [Rantala et al., 2009]. The authors designed three new interaction methods (scan, sweep, and rhythm) for reading braille characters represented on mobile touch-screen device. The evaluation experiments indicated that the participants could accurately (91-97 %) recognize individual braille characters. The authors used Nokia 770 Internet Tablet (90 mm x 55 mm) equipped with a piezoelectric actuator embedded under the touch-screen of the device. The first reading method was called braille-scan that used a traditional six-dot (2x3) braille coding layout. Users can read the characters by moving a stylus on the screen from dot to dot. The numbering of dots in this method is presented in figure 2.5 [Rantala et al., 2009]. The second reading method was braille-sweep. In this method, the dots were laid out horizontally instead of the standard matrix, as presented in figure 2.6. The third reading method was braille-rhythm. In this method, braille characters are presented as temporal tactile patterns. Reading a braille character starts by touching the screen at any location to begin the feedback and by keeping the stylus on the screen until the feedbacks for all six dots are presented. Figure 2.7 shows the feedback provided for letter “c” using the braille-rhythm method.

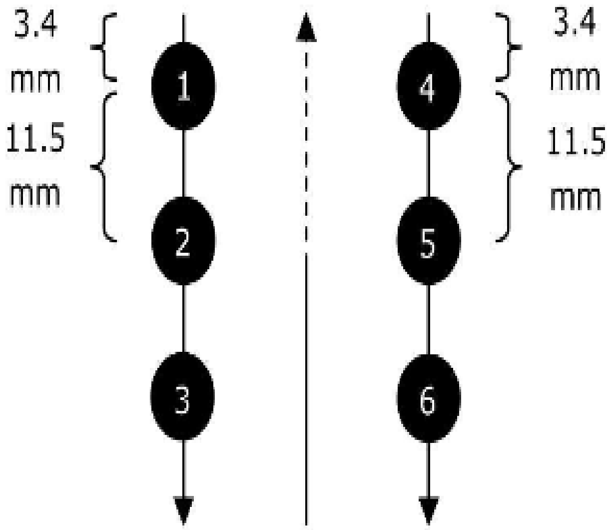


Figure 2.5 Numbering of dots in braille-scan method [Rantala et al., 2009].

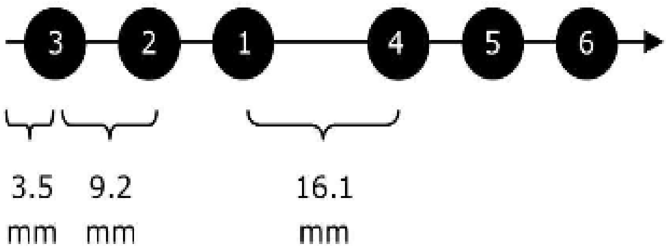
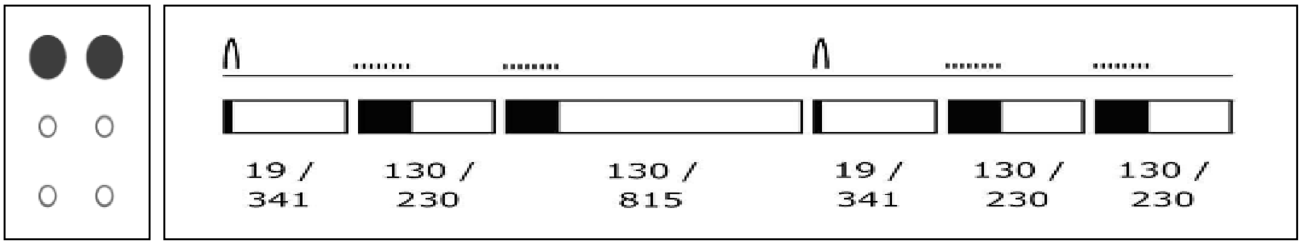


Figure 2.6 Braille-sweep method for reading horizontally aligned braille dots [Rantala et al., 2009].



(a) (b)

Figure 2.7 The braille-rhythm method (a) traditional braille letter 'c', (b) the feedback provided for letter 'c' using the rhythm method (pulse duration (ms) / silent interval before the next dot (ms)) [Rantala et al., 2009].

UbiBraille is a vibro-tactile braille reading device that uses six vibro-tactile actuators to represent braille coding [Nicolau et al., 2013]. This wearable system simultaneously actuates the user index, middle, and ring fingers of both hands, providing fast and mnemonic output. The approach emulates the traditional braille writing mechanism but with vibro-tactile feedback, where each actuator represents one dot of the six braille cell dots. Figure 2.8 presents the UbiBraille prototype, and how it views the 'h' letter in braille coding. The experiments conducted with 11 blind persons showed 82% of accuracy rate.

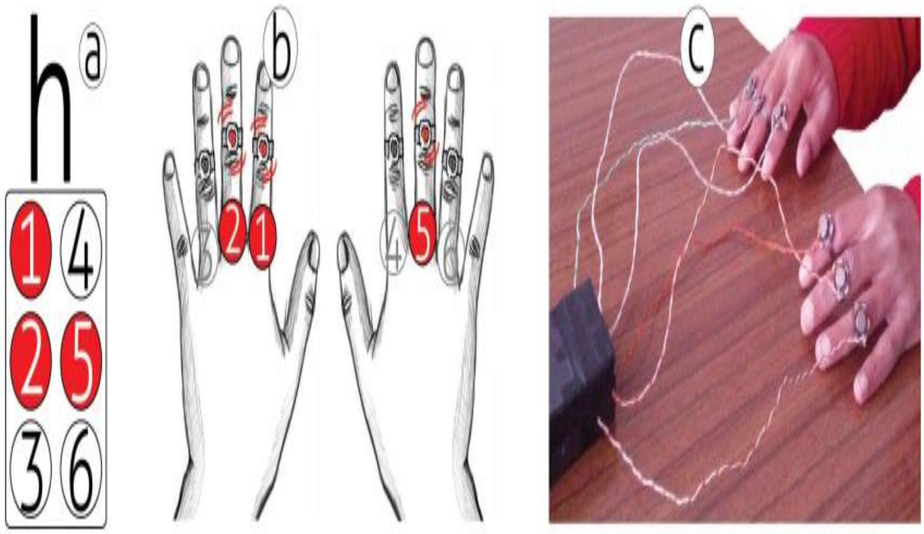


Figure 2.8 UbiBraille prototype, (a) representing the letter 'h' in English braille coding, (b) representing the letter 'h' on the index, middle, and ring fingers, (c) vibrators of UbiBraille [Nicolau et al., 2013].

Braille window system [Prescher et al., 2010] proposed a manner to enable visually impaired persons access to Microsoft windows systems. The system consists in a tactile display with a pin-matrix of 120 columns and 60 rows. The tactile display presents six separated regions (header region, view type region, structure region, detail region, window title region, and the main region) that enable the user to receive different types of information simultaneously. Figure 2.9 presents a prototype of the planar tactile display, and figure 2.10 presents the structure of the six regions [Prescher et al., 2010].

Figure 2.9 Prototype of the planar tactile display of the braille window system [Prescher et al., 2010].

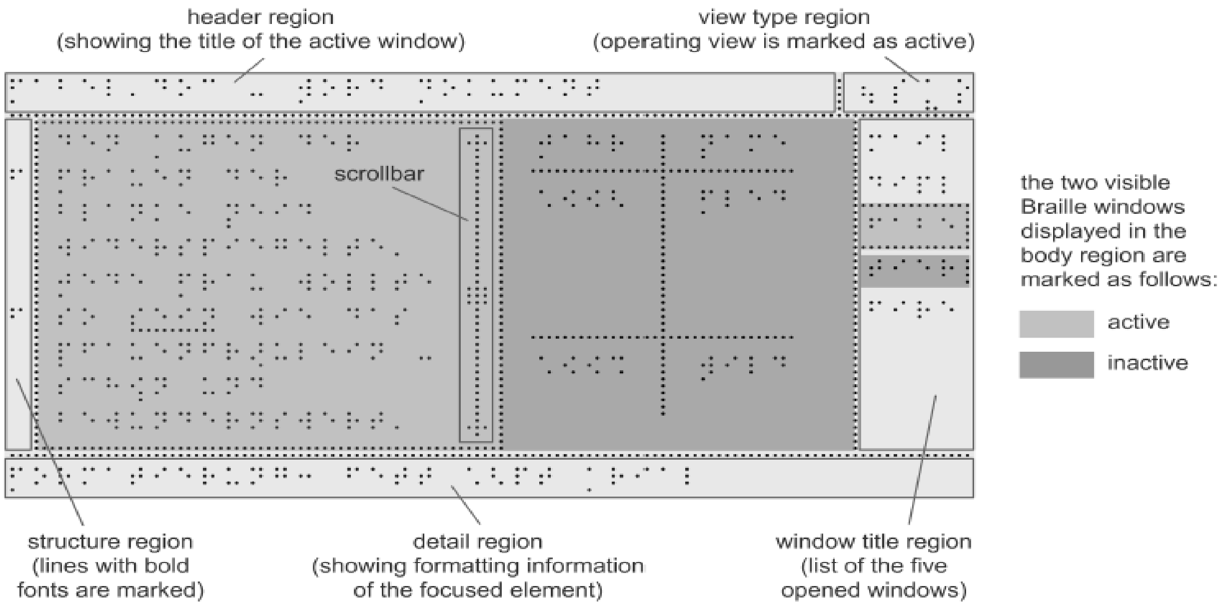


Figure 2.10 Structure of the six regions of the braille window system [Prescher et al., 2010].

The main region contains braille coding and graphics. The system proposes four different types of views namely outline, symbol, operating, and layout. The outline view presents a quick overview by presenting the content of a document as abstract rectangles. The operating view displays all of the content in braille coding. Spatial relationships in addition to braille coding are presented in the symbol view. The layout view provides a direct access to the graphical representation of a window. Figure

2.11 presents the four types of views. If the content of the main region (braille area) exceeds its dimensions, a tactile scrollbar (located to the right of the content) or scroll arrow (located below within the braille area) appears. The authors proposed four types of tactile scroll bars and three types of scroll arrows. Figure 2.12 presents the proposed scrollbars and scroll rows [Prescher et al., 2010]. The authors evaluated these scroll bars and scroll arrows with three blind subjects, the results have shown that a single line of dots with a slider with a size of 3 x 3 pins is the best solution to represent a scroll bar (cf. figure 2.12.a.I).

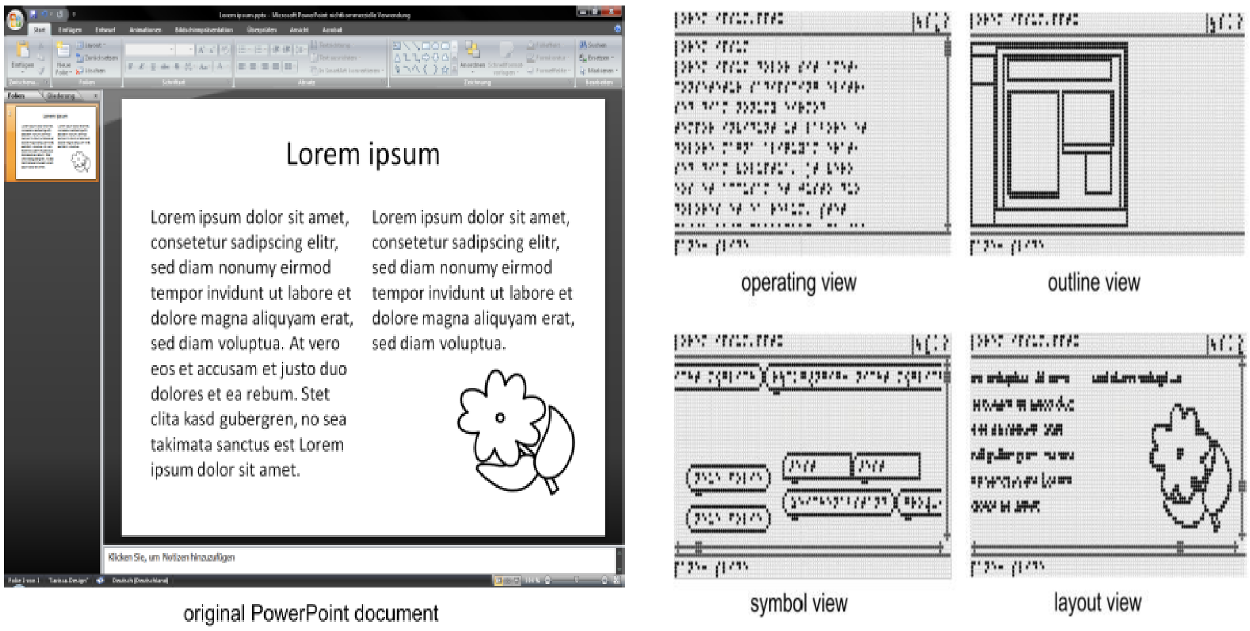
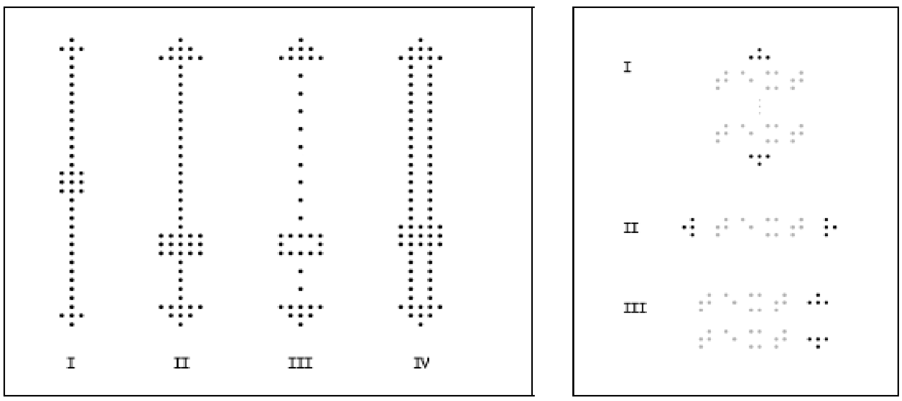


Figure 2.11 Four different views presented by the braille window system [Prescher et al., 2010].



(a) (b)

Figure 2.12 Designs of scroll-bars and scroll arrows, (a) four designs of tactile scroll-bars for the main region, (b) three designs of scroll arrows within braille area [Prescher et al., 2010].

A qualitative evaluation experiment has been conducted with eight blind subjects. The 2 hours experiment consists in 21 tests for each blind participant. The tests include many sub-tasks such exploration the view types, exploration the Braille areas, and exploration the main region. Multiple answers are allowed. 62.5% of participants evaluated the region structure as efficient. 37.5% of participants described the exploration as intuitive.

The participants have evaluated also the interaction aspects of the system. The participants have been asked to support a value between 0 and 5 to describe the efficiency of each interaction aspect. The minimum value 0 indicates 'very bad', and the maximum value 5 indicates 'very good'. Navigation inside a document has been described as 3.8 (76% of the maximum value). Interaction with Braille areas and windows has been described as 4.4 (88% of the maximum value).

To summarize the Braille-coding oriented tactile vision substitution systems: some systems have been proposed to allow visually impaired persons entering texts on mobile touch-screen devices, either by gestures, or by direct pointing, such TypeInBraille [Mascetti et al., 2011] and BrailleType [Oliveira et al., 2011]. These systems achieved different speeds in correct entering of Braille characters: 6.3 wpm for TypeInBraille, and 1.45 wpm for BrailleType. Considering that the speed average of entering texts via VoiceOver text entry technique is 2.11 wpm.

In what concerns the applications oriented to replace refreshable Braille displays. The presented systems use either mobile touch-screen devices such VBGhost [Milne et al., 2013]; or they use other special devices to present Braille characters such Braille window system [Prescher et al., 2010]. Some presented systems use vibro-tactile feedbacks to enhance recognizing the Braille characters by visually impaired persons such V-braille [Jayant et al., 2010], Body-Braille [Ohtsuka et al., 2008], and UbiBraille [Nicolau et al., 2013]. The time average and the accuracy rate for reading Braille characters are different between the presented systems. Table 2.1 presents a short comparison of accuracy rates and reading time averages between the presented systems.

Table 2.1 Accuracy rates and reading time averages between the presented systems.

System	**Accuracy rate (%)**	**Time average to read a Braille character (Seconds)**
V-Braille [Jayant et al., 2010]	90%	15.4 seconds
Body-Braille [Ohtsuka et al., 2008]	80%	0.95 seconds
Vibro-tactile braille-based approach [Rantala et al., 2009]	94%	4.7 seconds
UbiBraille [Nicolau et al., 2013]	82%	1 second

It is remarkable in table 2.1 that the time averages of the two best systems (15.4 seconds for V-Braille and 4.7 seconds for Vibro-tactile braille-based approach) are significant larger than the average times of other systems (0.95 Body-Braille and UbiBraille).

2.3.2 Vibration-Oriented Tactile Vision Substitution Systems

Many authors have proposed the attachment of vibro-tactile actuators on users' body for working as mnemonic information [Kammoun et al., 2012] [Israr et al., 2014] [MacLean et al., 2003]. Adding different vibration patterns while interacting with touch-screen devices can convey more semantic information, such as user's scrolling rate, and position on the screen [Yatanic et al., 2009] [Poupyrev et al., 2002].

Researches in the field of vibro-tactile interactions begin as early as the 1920s, with a system that tested the feasibility of transferring speech into vibro-tactile stimuli [Choi et al., 2013]. A vision substitution system by tactile image projecting has been proposed in 1969 by [Bach-y-Rita et al., 1969]. The system consists in 400 solenoid stimulators (twenty x twenty) built into a chair. The stimulators are spaced 12 mm apart, and have 1 mm diameter [Bach-y-Rita et al., 1969]. The solenoid stimulators vibrate against the skin of the back (cf. figure 2.13). A fixed television camera scans objects on a table in front of a subject. The system transforms the captured image into vibro-tactile stimuli using the 400 stimulators [Bach-y-Rita et al., 1969].

The system has been evaluated with six blind persons, and with six sighted persons. The subjects have been trained first to discriminate vertical, horizontal, diagonal, and curved lines. They are trained then to discriminate combinations of lines such squares, triangles, and circles. After one hour of training, the subjects have been asked to achieve two phases of evaluation. In the first evaluation phase, a series of lines have presented in vibro-tactile modality, and the subjects have been asked to detect their orientation. In the second evaluation phase, the subjects have been asked to recognize a series of shapes presented in vibro-tactile modality. Table 2.2 presents the accuracy rate for each evaluation task. Table 2.3 presents the average time for each evaluation task [Bach-y-Rita et al., 1969].

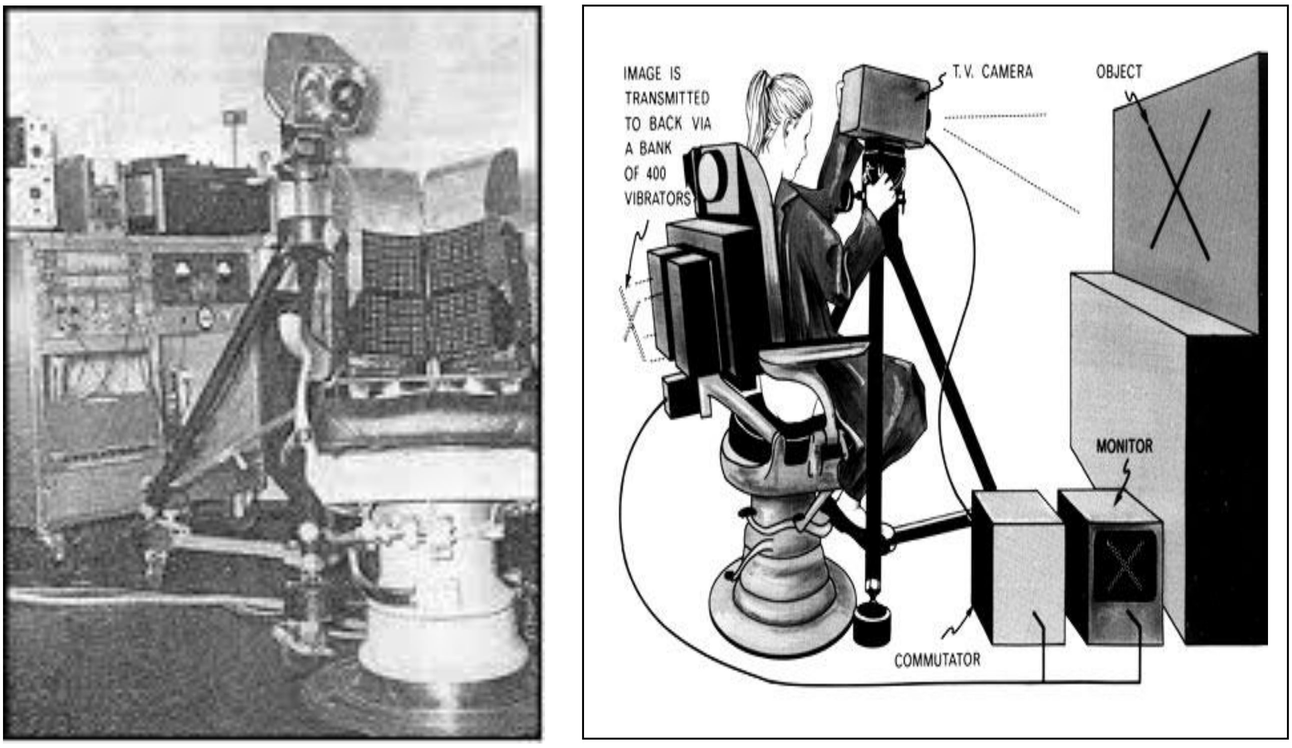


Figure 2.13 Bach-y-Rita tactile vision substitution system [Bach-y-Rita et al., 1969].

Table 2.2 Accuracy rates for each evaluation task in Bach-y-Rita system [Bach-y-Rita et al., 1969].

	Line orientation discrimination	Shapes discrimination
Blind participants N=6	99.6%	82.9%
Sighted participants N=6	100%	97.5%

Table 2.3 Average times for each evaluation task in Bach-y-Rita system [Bach-y-Rita et al., 1969].

	Line orientation discrimination	Shapes discrimination
Blind participants N=6	1.2 seconds	8.4 seconds
Sighted participants N=6	1.1 seconds	2.8 seconds

This system has been developed to benefit the high sensitivity and mobility of the tongue [Bach-y-Rita et al., 1998]. A 49-point (7x7) electro-tactile array has been developed to evaluate the ability of form perception via tongue. The dimensions of this display device are 1.8×1.8 cm (cf. figure 2.14). The display was held in front of the face, and the tongue was placed against the array [Bach-y-Rita et al., 1998].

Figure 2.14 A 7x7 electro-tactile array with a U.S. penny for size comparison [Bach-y-Rita et al., 1998].

12 tactile patterns have been evaluated with 5 sighted persons. The 12 tactile patterns are four circles, four squares, and four triangles. These tactile patterns are sized to 4×4, 5×5, 6×6, and 7×7 arrays (cf. figure 2.15) [Bach-y-Rita et al., 1998]. The shape recognition performance via the tongue was 79.8%.

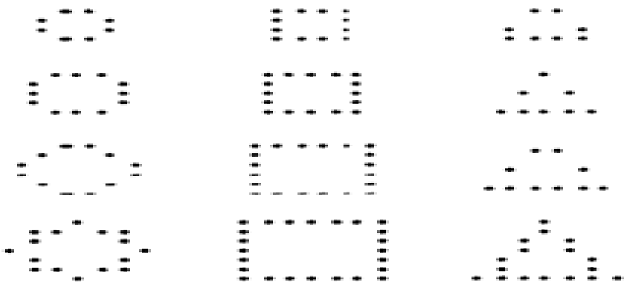


Figure 2.15 Tactile patterns sized to 4x4, 5x5, 6x6, and 7x7 arrays [Bach-y-Rita et al., 1998].

The system has been developed again with a model of 12x12 array of electrodes set in the mouth (cf. figure 2.16) [Bach-y-Rita et al., 2002] [Kaczmarek, 2011]. The system evokes tactile sensations within the tongue at the location of the activated electrode, by passing a local electric current through the skin.

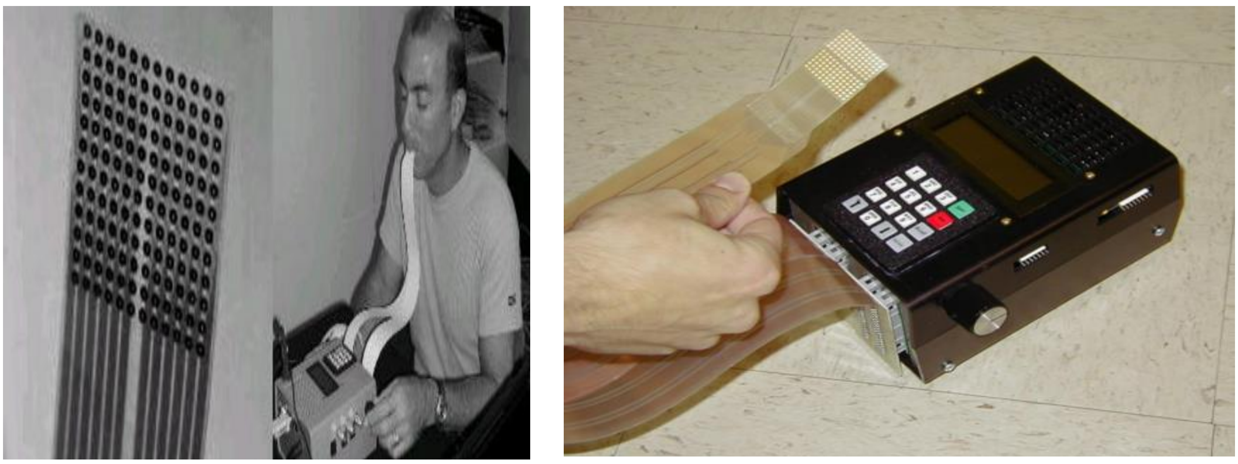


Figure 2.16 A tongue display unit (TDU) with a model of 12x12 array of electrodes [Bach-y-Rita et al., 2002] [Kaczmarek, 2011].

Optacon (OPtical to TActile CONverter), is one of oldest vision substitution systems that proposed a vibro-tactile feedback for printed documents [Bliss et al., 1970]. It translates a written word into a scanned display (cf. figure 1.3 in chapter 1). The system provides an electromechanical device that enables blind people to read printed materials using a camera to be moved over printed characters, and a tactile array to output a tactile representation of the scanned characters [Goldish et al., 1974]. The blind person holds the camera by a hand and moves it over a line of printed characters, and the index finger of the another hand rests on a tactile array of 24×6 vibrating pins. As the camera recognizes a character (depending on the optical contrast and on the shape of the character), the recognized character is converted to a shape made by the vibrated pins [Goldish et al., 1974].

Tactile Television [Collins et al., 1970] proposed the same principle, designing a pictorial mapping device for mapping an image to an array of vibrating points located on the back of the device. The system allowed blind subjects to determine the position, size, shape, and orientation of visible objects and to track moving targets. The 400 tactile stimulators are situated in a 20x20 matrix in contact with a 10-inch square of skin [Collins et al., 1970].

D.E.L.T.A. "Dispositif Electronique de Lecture de Texte pour Aveugles" [Conter et al., 1986] is a device has been designed to enable visually impaired persons reading any kind of font-type characters printed for any support (plane or not). This optical character reader consists in a micro-camera connected to a specialized pattern recognition processor. The recognized characters are generated in a braille tactile form, on a specific tactile output. The mean efficiency of the system is about 95% for most font-types. Reading can be operated at up to 15 characters per a second. Figure 2.17 presents the components of D.E.L.T.A [Conter et al., 1986].

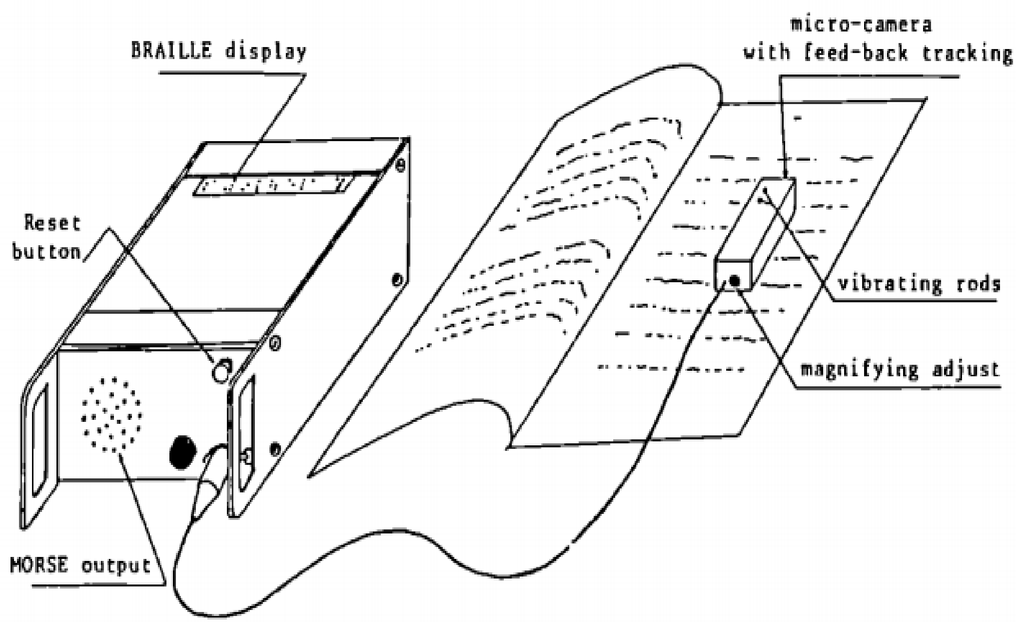


Figure 2.17 Components of D.E.L.T.A system [Conter et al., 1986].

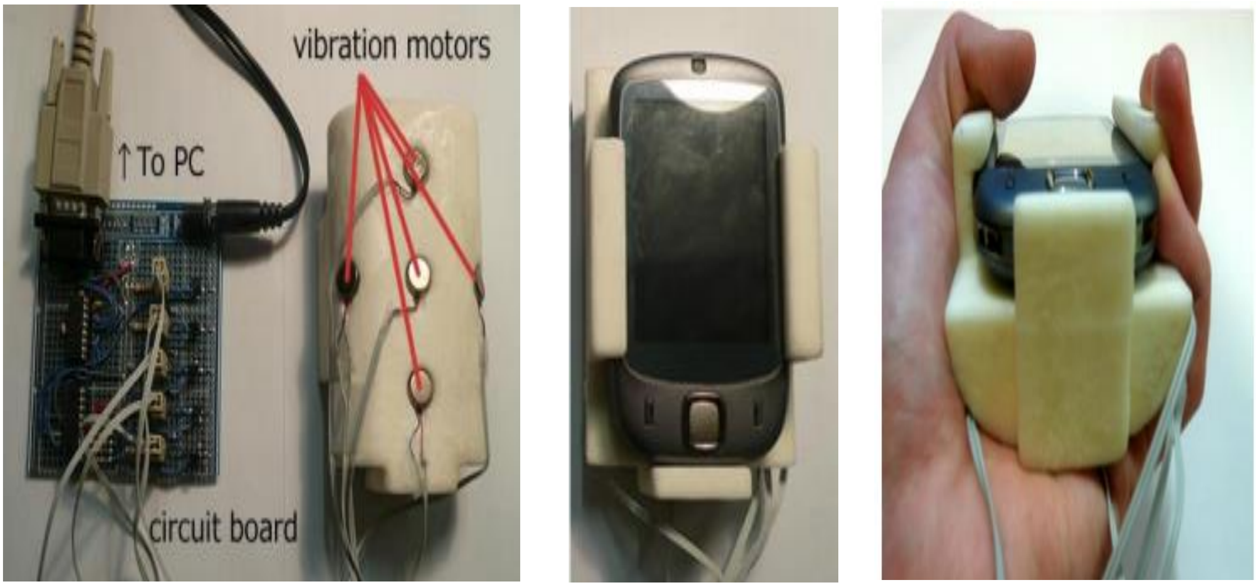
A rich tactile output system has been proposed to evaluate the potential of rich tactile notifications on mobile phones [Sahami et al., 2008]. To explore the possible design space, the authors included 6 actuators in a mobile phone prototype to find out about the user experience that can be created with multi-vibration output in a handheld device. The parameters that have been studied in the conducted experiments are the location of the active actuators, the intensity of the vibration, and the variation of the vibration over time [Sahami et al., 2008]. The authors developed a prototype that allowed them to create a rich tactile output in a device equivalent in size and shape to a typical mobile phone Nokia

N-70. Figure 2.18 shows the used mobile phone with 6 vibration motors. Four vibration motors were located at the four corners of the phone, and two motors were in the center of the phone [Sahami et al., 2008]. The first experiment showed that participants could discriminate between left and right vibration motors, as well as top and bottom, with a correct recognition rate of 75% on average. Users showed a nearly similar correct detection rate for actuators in the four corners (with an average rate of 73%), and significantly lower recognition rate for the actuators in the middle of the device. To study the ability of participants for discriminating between vibration patterns, the authors designed three vibration patterns. The first pattern was called circular pattern, where in each moment one vibration motor was on, the second pattern was called "Top-Down" with two motors on (motors with numbers 1 and 5, or 0 and 4), and the last one was "Right-Left" with two motors on at the same time (motors 0 and 1, motors 2 and 3, or motors 4 and 5) [Sahami et al., 2008]. The accuracy rate for the first pattern "circular" was 82%, the second pattern "Top-Down" was 51%, and the last one "Right-Left" was 68%.

Figure 2.18 Six vibration motors integrated in a mobile phone, placed to maximize the distance between them. The motors can be controlled using a Bluetooth connection [Sahami et al., 2008].

Tactons, or tactile icons, are structured, abstract non-visual messages that cover a range of different vibration pattern parameters as frequency, amplitude, duration, rhythm, and location [Bliss et al., 1970]. An icon is defined as an image, picture, or symbol representing a concept. Icons are very powerful ways for displaying visual information [Bliss et al., 1970]. Tactons can represent complex visual concepts (icons). The range of used frequencies in Tactons is 20 – 1000 Hz, and the maximum sensitivity is considered around 250 Hz. The number of discrete values that can be differentiated is nine different levels. The used waveforms are sine waves and square waves. Fingers are used for vibro-tactile displays because of their high sensitivity to small amplitudes and their high spatial acuity [Bliss et al., 1970].

SemFeel proposes a tactile user interface for mobile touch-screen devices to inform the user about the presence of an object on which he/she touches on the screen, and to provide additional semantic information about that item [Yatani et al., 2009]. The proposed system has five micro vibration motors embedded in different locations in the back-side of a mobile touch-screen device (top, bottom, right, left, and center). Figure 2.19 presents SemFeel hardware prototype. The system proposes eleven vibration patterns: Five positional patterns (top, bottom, right, left, and center), four linear pattern (top-bottom, bottom-top, right-left, and left-right), and two circular (clockwise and counter-clockwise). For the linear and circular vibration patterns, different levels of vibration strength are used to generate a smoother transition of vibration. Figure 20 presents the eleven vibration patterns of SemFeel. Figure 2.21 presents examples of different levels of vibration strength during right-to-left vibration pattern [Yatani et al., 2009]. The results demonstrated that the participants could distinguish the eleven patterns at accuracy 83.3 – 93.3%.



(a) (b) (c)

Figure 2.19 SemFeel hardware prototype, a) the circuit board and the mobile touch-screen device with five vibration motors on the backside, b) the front side of the mobile device, c) the special sleeve for the SemFeel prototype [Yatani et al., 2009].

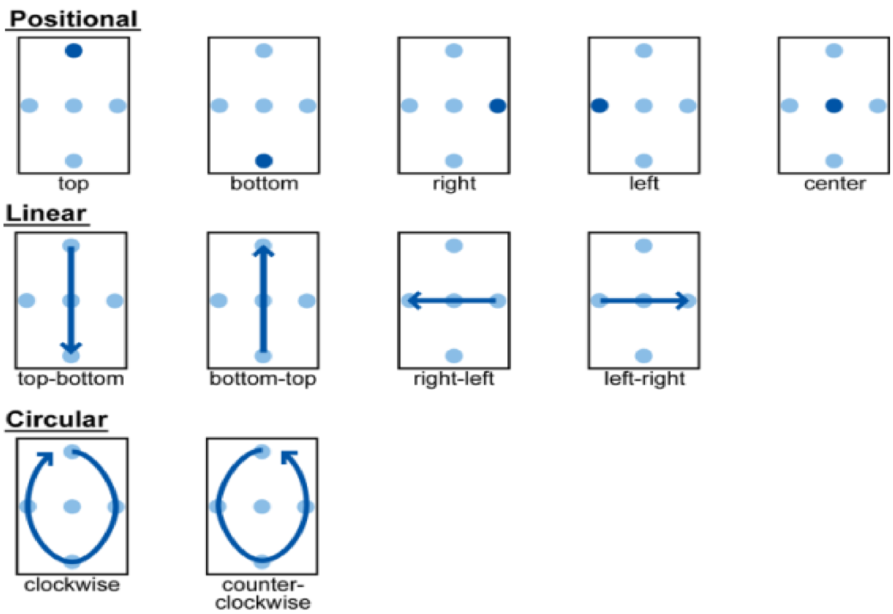


Figure 2.20 The eleven vibration patterns of SemFeel [Yatani et al., 2009].

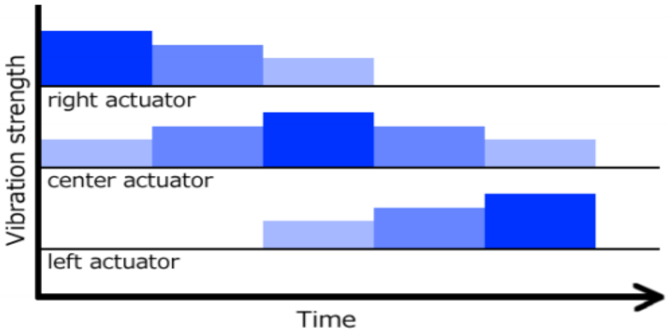


Figure 2.21 Different levels of vibration strength during right-to-left vibration pattern [Yatani et al., 2009].

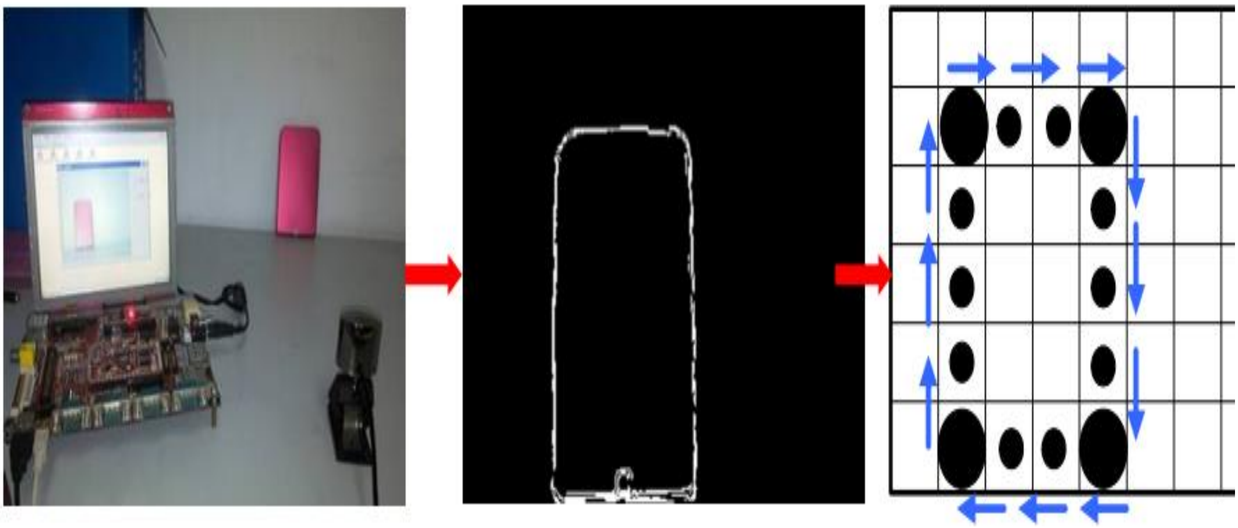
A vibro-tactile vest for perceiving the contour has been designed by [Juan et al., 2012]. The authors proposed an approach to extract an image contour and to represent it by an array of 48 vibration motors (6x8) located inside a vest in order to allow a visually impaired user feeling an object contour by vibration stimuli. Figure 2.22 views the vibro-tactile vest [Juan et al., 2012]. The system is composed of a camera for capturing the object image, an array of 48 vibrating motors, and an embedded system to control the vibrating motors. The diameter of each vibrator is 10 mm, the weight is 17g, and the frequency range is 200-300 Hz. This system is similar to that proposed by [Bach-y-Rita et al., 1969] with difference in the number of stimulators, and the distance between them (cf. figure 2.13). Table 2.4 presents some differences between the two approaches.

Table 2.4 Differences between the two vibro-tactile approaches proposed by [Juan et al., 2012] and [Bach-y-Rita et al., 1969].

	Vibro-tactile approach proposed by [Juan et al., 2012]	Vibro-tactile approach proposed by [Bach-y-Rita et al., 1969]
Number of stimulators	48 (6x8)	400 (20 x 20)
Diameter of each stimulator	10 mm	1 mm
Distance between stimulators	20-30 mm	12 mm

Figure 2.22 The vibro-tactile vest [Juan et al., 2012].

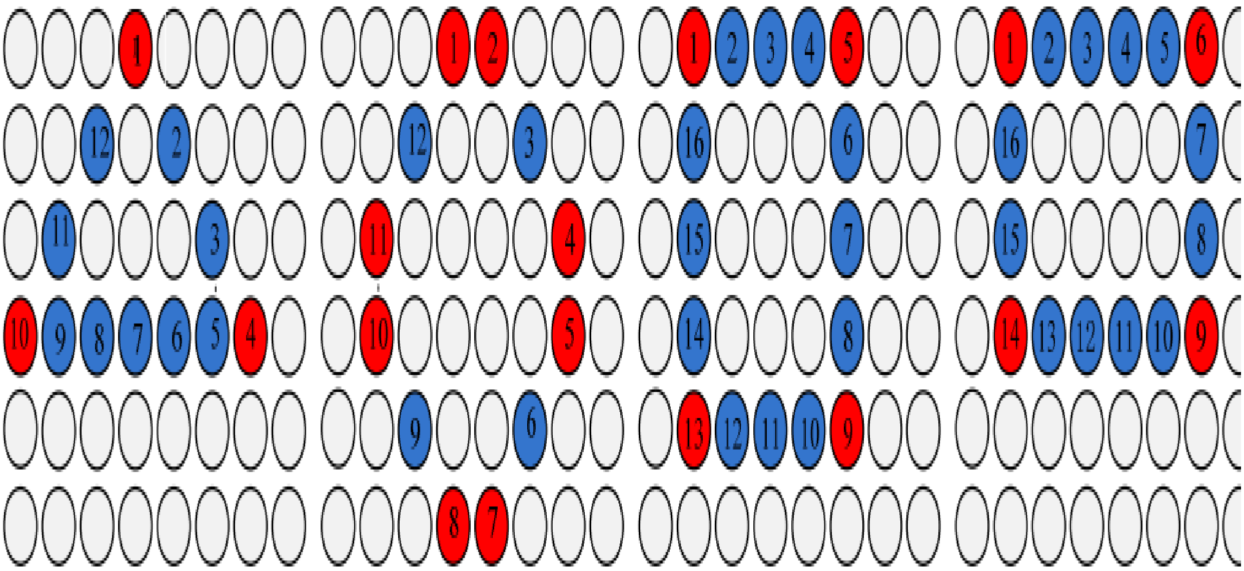
The authors proposed a temporal-spatial dynamic coding method to convert the extracted 2D contour into vibro-tactile stimuli. Figures 2.23(a), 2.23(b), and 2.23(c) view examples of using the proposed temporal-spatial dynamic coding [Juan et al., 2012]. In figure 2.23(c) the contour is represented by large and small points (black circles). Each large circle represents a vertex (the vibration intensity is controlled by an applied voltage of 3V for large points), and small points represent non-vertex elements (the vibration intensity is controlled by an applied voltage of 1V). Arrows represent how the sequence of vibration is activated.



(a) (b) (c)

Figure 2.23 An example of a temporal-spatial representation for an object contour. (a) capturing an image for the object, (b) detecting the object contours, (c) a temporal-spatial representation of the object contours [Juan et al., 2012].

The authors evaluated the capacity of the system to represent letters and shapes. Four types of shapes have been evaluated to be represented by the suggested system, which are: triangles, circles, squares, and rectangles. Figure 2.24 represents some examples of the evaluated shapes [Juan et al., 2012]. The Latin alphabet letters have also been evaluated by the suggested system (cf. figure 2.25) [Juan et al., 2012]. In figures 2.24 and 2.25, each red point represents a vertex, and the numbers represent the vibration sequence. The average correct recognition rate for letters and shapes was 82%, and the mean correct identification rate of image contour was 91.8%.



(a) Triangle (b) Circle (c) Square (d) Rectangle

Figure 2.24 A representation of four shapes by the vibro-tactile patterns, (a) a triangle, (b) a circle, (d) a square, (e) a rectangle [Juan et al., 2012].

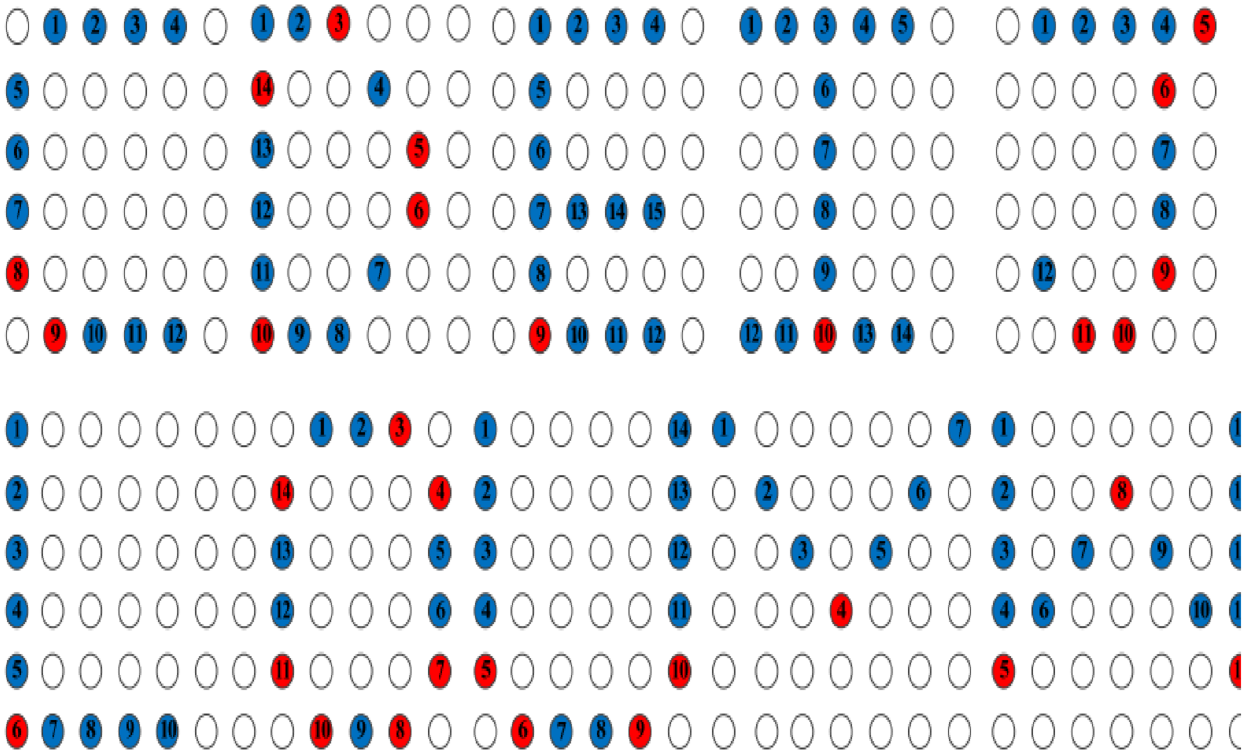


Figure 2.25 Representation of ten Latin letters (C, D, E, I, J, L, O, U, V, W) [Juan et al., 2012].

STIMTAC [Amberg et al., 2011] is a touchpad device that supports friction reduction using the technique of "squeeze film effect" [Biet et al., 2007] between the plate surface and the finger (cf. figure 2.26). STIMTAC is acting as a texture display by creating an air bearing between the user finger and the device surface [Amberg et al., 2011]. The air bearing is generated by ultrasonic vibrations on the touched position of the device surface. Controlling this vibration allows generating tactile feedbacks.

Figure 2.26 STIMTAC Model [Amberg et al., 2011].

To summarize the vibration-oriented tactile vision substitution systems: many systems have been designed to convey more semantic information by interacting different vibration patterns. In some systems, the vibration stimulators are placed on the back such that system designed very early by Bach-y-Rita [Bach-y-Rita et al., 1969], and the vibro-tactile vest [Juan et al., 2012]. In other systems, the vibration stimulators are placed in the mouth, and the stimuli have been perceived via the tongue, such the system designed by [Bach-y-Rita et al., 2002] [Kaczmarek, 2011]. The majority of other presented systems are navigated by the hands; either, a direct navigation by the hand such STIMTAC [Amberg, et al., 2011], or by using an optical character reader such D.E.L.T.A. "Dispositif Electronique de Lecture de Texte pour Aveugles" [Conter et al., 1986]. Some presented systems are oriented to the mobile devices such SemFeel prototype [Yatani et al., 2009].

2.3.3 Spatial-Oriented Tactile Vision Substitution Systems

Access to graphics and other two dimensional information is still limited for visually impaired persons [Goncu et al., 2011]. In this section, the focus will be given for studies and researches on non-visual perceiving graphics and 2-dimensional layout using tactile sensation. Previous studies indicated that visually impaired persons can construct mental maps of spatial relationships between multiple objects or locations using tactile sensation [Thinus-Blanc et al., 1997] [Ungar, 2000].

Some researches have been proposed to support audio-tactile feedbacks in order to perceive the spatial information, such:

- GraCALC, an accessible graphing calculator [Goncu et al., 2015];
- Invisible_Puzzle, a mobile application that proposes a set of 6 sonification techniques for recognizing simple shapes on touch-screen devices [Gerino et al., 2015];
- "Drawing by ear system", a system for generating sonified graphs [Brown et al., 2003];
- "Sonification Sandbox": a toolkit for auditory graphs [Walker et al., 2003];
- EVITA (Enabling Visually Impaired Table Access) [Yesilada et al., 2004];
- Tac-tiles: a multimodal system to present pie charts for visually impaired [Wall et al., 2006];
- AudioGraph, a tool for communicating graphical information to visually impaired persons using music [Alty et al., 1998].

Tactos is a perceptual interaction system [Hatwell et al., 2003] that consists in three elements (cf. figure 2.27):

- tactile simulators (two braille cells with 8 pins) represent a tactile feedback system;
- a graphics tablet with a stylus (represents an input device); and
- a computer [Tixier et al., 2013].

The graphics tablet and the stylus allow the user to explore graphical contents on the screen such as circles, rectangles, and characters. While the user explores the contents, the system transforms pixels under the stylus into tactile stimulation on the braille cells. 30 prototypes of Tactos have been released, to be used by different users in many domains. Tactos has been successfully used to recognize simple and complex shapes. The device has been used in geometry teaching domain in an institution for visually impaired and blind children [Tixier et al., 2013] [Gapenne et al., 2003]. Tactos also allowed psychology researchers to propose and develop new paradigms for studying perceptions and mediated communication of blind persons [Tixier et al., 2013] [Gapenne et al., 2003].

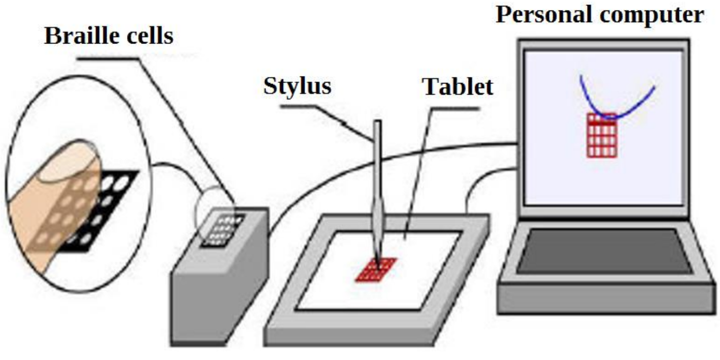


Figure 2.27 Tactos components [Hatwell et al., 2003].

GraVVITAS (Graphics Viewer using Vibration, Interactive Touch, Audio and Speech) is a multimodal system for presenting accessible graphics [Goncu et al., 2011]. The system uses a multi-touch display for tracking the position of the user's fingers, supported with a haptic feedback provided by small vibrating motors, and an audio feedback for providing non-geometric information about graphical elements. The authors used a Dell Latitute XT tablet with pen and touch input using capacitive sensors. The tablet can detect and track user's touches on the touch-screen. The system provides a haptic feedback using a low cost data glove with vibrating actuators. Figure 2.28 presents a prototype of GraVVITAS system.

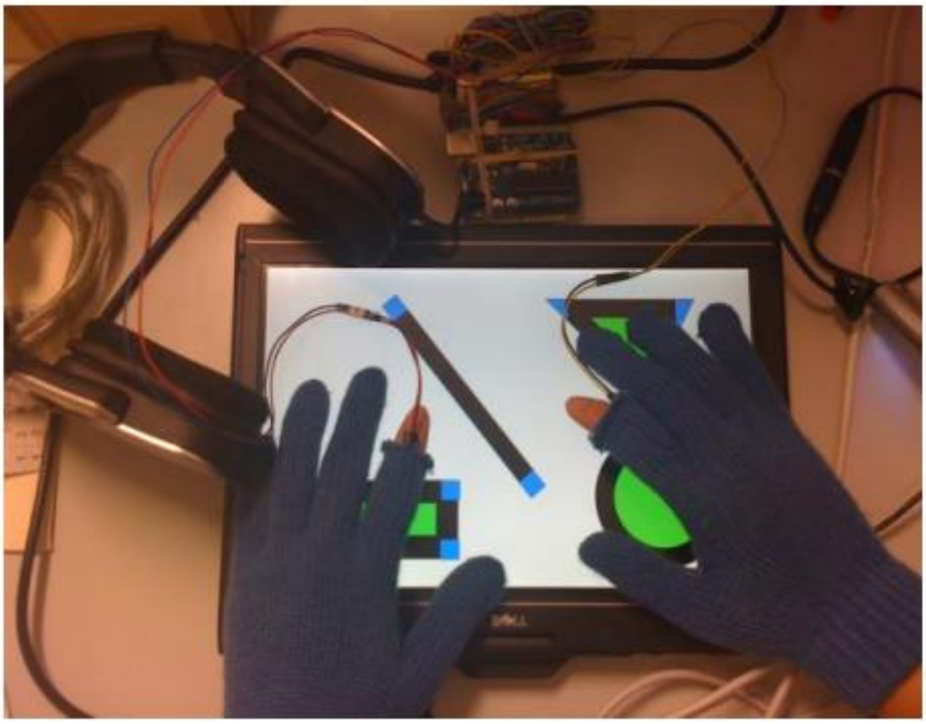


Figure 2.28 GraVVITAS components [Goncu et al., 2011].

To evaluate the ability of visually impaired persons to determine the geometric properties (positions and shapes), the authors conducted a usability study using simple graphics containing one to four geometric shapes (line, triangle, rectangle and circle). Figure 2.29 views the used shapes. Each shape had a low intensity interior color and a thick black boundary around it. This means that the intensity of the haptic feedback is greater when the finger touches the shapes boundary.

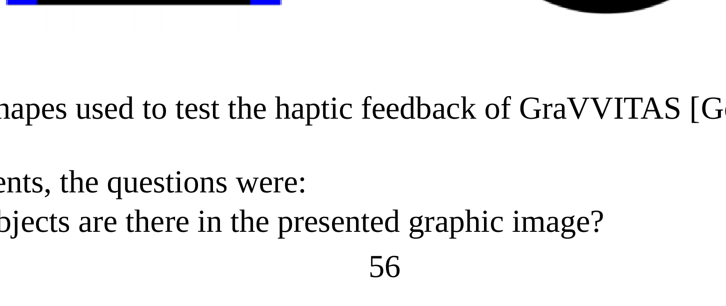


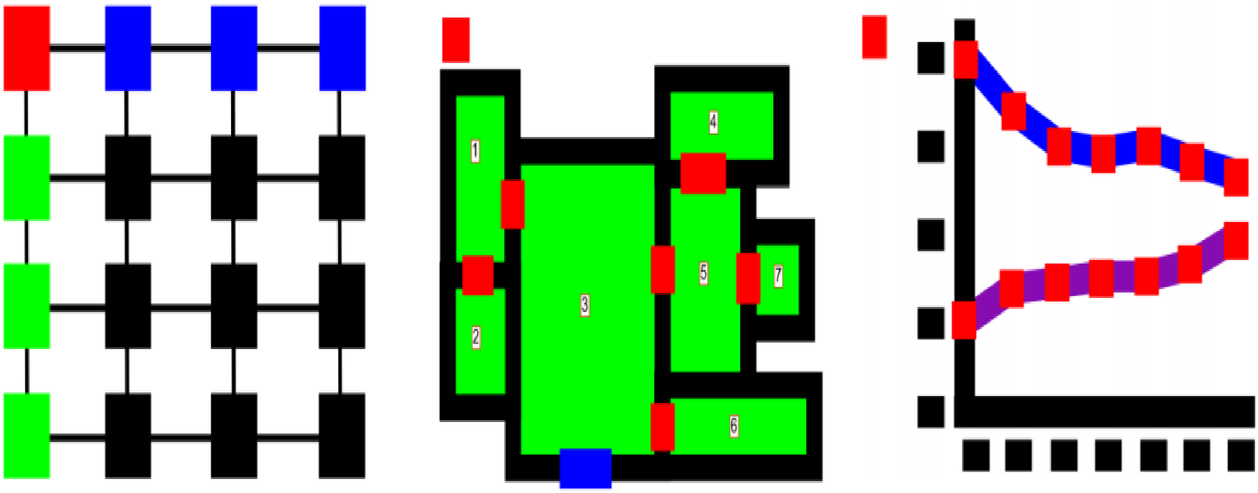
Figure 2.29 Shapes used to test the haptic feedback of GraVVITAS [Goncu et al., 2011].

During the experiments, the questions were:

- how many objects are there in the presented graphic image?

- what kind of geometric shape is each object?

The authors observed that participants used two quite different strategies to identify shapes. The first one was to find the corners of the shapes, and then to carefully trace the boundary of the object using one or two fingers. The second strategy was to use a single finger to repeatedly perform a quick vertical and/or horizontal scan across the shape. 6 of 8 participants answered correctly to all the questions about the numbers and types of shapes. In the second conducted experiment, the authors tested three common kinds of complex 2D content that were quite different to each other: a table, a floor plan, and a line graph. All the tested shapes apply a condition that objects should not be smaller than 5 mm. Figure 2.30 presents the evaluated 2D shapes. The authors asked the participants many questions about the design of each shape, for example: how many cells in the table, how many rooms in the floor plan, etc. The participants found that the floor plan is the most difficult to be recognized, followed by the line graph, and then by the table. All the questions about the table and the line graph have been correctly answered, and only two questions (of totally 18 questions) about floor plan received a wrong answer.



(a) (b) (c)

Figure 2.30 Complex 2-D objects used by GraVVITAS, (a) table, (b) floor plan, (c) line graph [Goncu et al., 2011].

Another approach for providing non-visual access to spatial information on touch-screen devices using a vibro-audio feedback has been proposed by [Giudice et al., 2012]. The system allows users to freely explore spatial information on a touch-screen and supports vibration patterns whenever a visual element is touched. The authors conducted three studies for evaluating comprehension of the relative relations and global structure of a bar graph (experiment 1), pattern recognition via a letter identification task (experiment 2), and orientation discrimination of geometric shapes (experiment 3). Figure 2.31 presents 3 examples of shapes displayed on the touch-based device for the three experiments [Giudice et al., 2012].

The system performance (with touch-based device) was compared to the same tasks performed using standard hard-copy tactile graphics. Results showed similar error performance between the two modes (touch-screen graphics and standard hard-copy tactile graphics) for all measures [Giudice et al., 2012]. The interface was based on a Samsung Galaxy tablet with a 7.0 inch touch-screen, with operating system Android version 3.2. All lines used in the graphics were rendered with a width of 8.9 mm. A constant vibration of 250 Hz has been applied for each rendered line.

(a) (b) (c)

Figure 2.31 Some examples of shapes displayed on the touch-based device for the three experiments, (a) bar graph, (b) letter identification, (c) orientation discrimination of geometric shapes [Giudice et al., 2012].

MaskGen system has been developed to interactively transpose illustrations of schoolbooks graphics into tactile graphics [Petit et al., 2008]. The system is dedicated to students with visual impairments. The tactile graphics are displayed on a specialized refreshable tactile device (called STReSS) [Levesque et al., 2008] (already presented in section 1.10, chapter 1). The authors evaluated this system on three scientific graphics (diagram, bar-chart, and map) with forty participants: twenty sighted adults, ten adults with visual impairments, and ten children with visual impairments. Three tactile rendering types have been used: dots, waves, and vibration (cf. figure 2.32). Results showed that the participants with visual impairments could use the system to explore illustrations and to answer questions about their content [Petit et al., 2008] [Levesque et al., 2008].

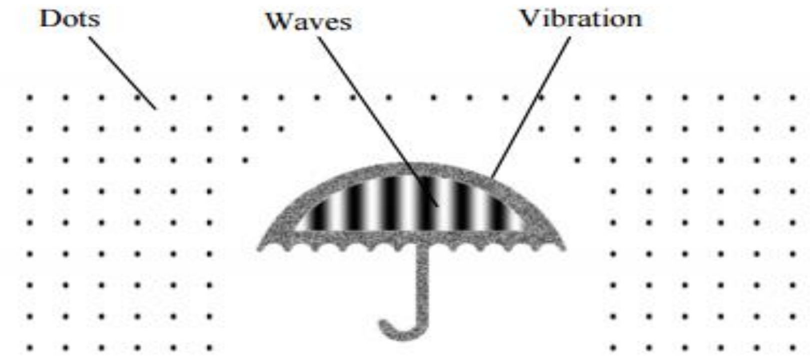


Figure 2.32 An example of a tactile graphic with the three tactile rendering types (dots, waves, and vibration) [Petit et al., 2008].

Many researches have been conducted to enhance access the visually impaired persons to charts and graphs. A small device has been designed by [Ebina et al., 1998] to display graphical information in tactile form. The device is composed of forty cells; each one contains sixteen actuators (matrix of 8×2 pins). Each actuator can be on or off. Users can touch the pin array and get a tactile sensation of the presented image. Experiments showed that participants were able to perceive maximum and minimum values, and other statistical values in simple charts [Ebina et al., 1998]. A similar device has been proposed by [Shinohara et al, 1998], but with a tactile surface that consists in 64×64 actuators on a total area of 200 mm ×170 mm. The actuators are very close to each other and can rise up between 0.1 mm and 10 mm. Users can get tactile graphical information by touching the pins raised at varying heights with fingers. Experiments showed that this device can give a precise tactile rendering of graphics, and can aid the participants to perceive various kinds of information [Shinohara et al, 1998].

A haptic approach has been proposed by [Ziat et al., 2007] to compare two methods of interaction depending on haptic recognition of shapes at different scales. The authors used Tactos [Gapenne et al., 2003] (already shown in section 2.3.1) to compare two scaling methods:

- the first one consists in a reduction of the sensor size and of its displacement speed (hand speed reduction);
- the second method consists in a straightforward increase in the dimensions of the rendered image.

Figure 2.33 presents how the system Tactos converts the graphics drawn on the graphical tablet to tactile graphics. Figure 2.34 presents the two scaling methods. Results showed that the recognition rate is closely dependent on the size of the figure, and that the navigation strategies used by the subjects are more suitable for method 2 (increasing the dimensions of the rendered image) than for method 1 (reduction of the sensor size) [Ziat et al., 2007].

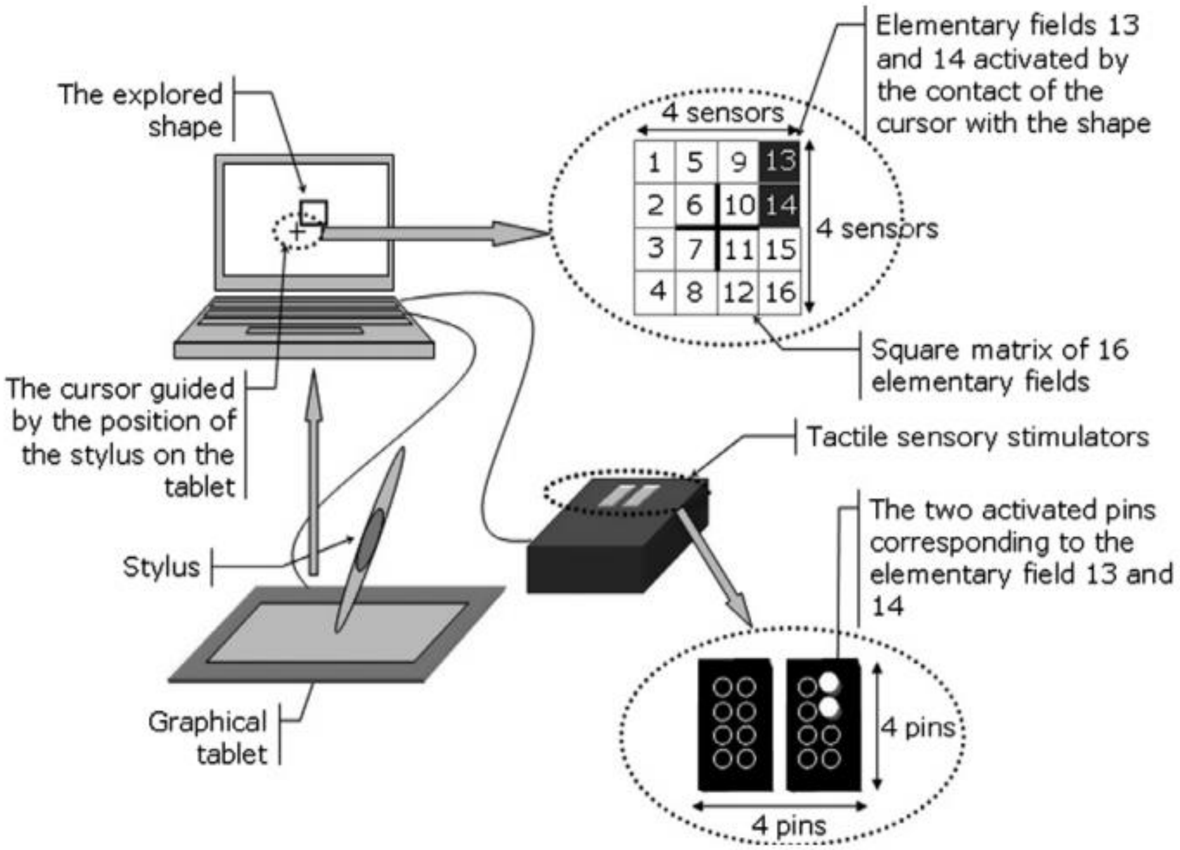


Figure 2.33 Tactos: an example of producing tactile graphics [Ziat et al., 2007].

The system consists in three components (cf. figure 2.33):

- a graphical tablet with a stylus,
- tactile sensory stimulators, and
- a computer.

The stimulators are two electronic Braille cells. Each Braille cell is consisted in 8 tactile pins (16.7 mm x 6.4 mm). The subject navigates the graphical tablet using a stylus. The system maps the stylus position on the graphical tablet to a virtual cursor on the computer screen. This mapping serves to detect the interaction between the stylus position and the outline of the explored figure. The virtual cursor consists in a square matrix of 16 elementary fields. When the virtual cursor is on the outline of the figure, the corresponding pins of the tactile sensory simulators are raised. For example, in figure 2.33, the elementary fields 13, and 14 of the virtual cursor are activated by the contact of the cursor with the figure. These two activated fields are corresponded to two activated pins in the tactile sensory stimulators.

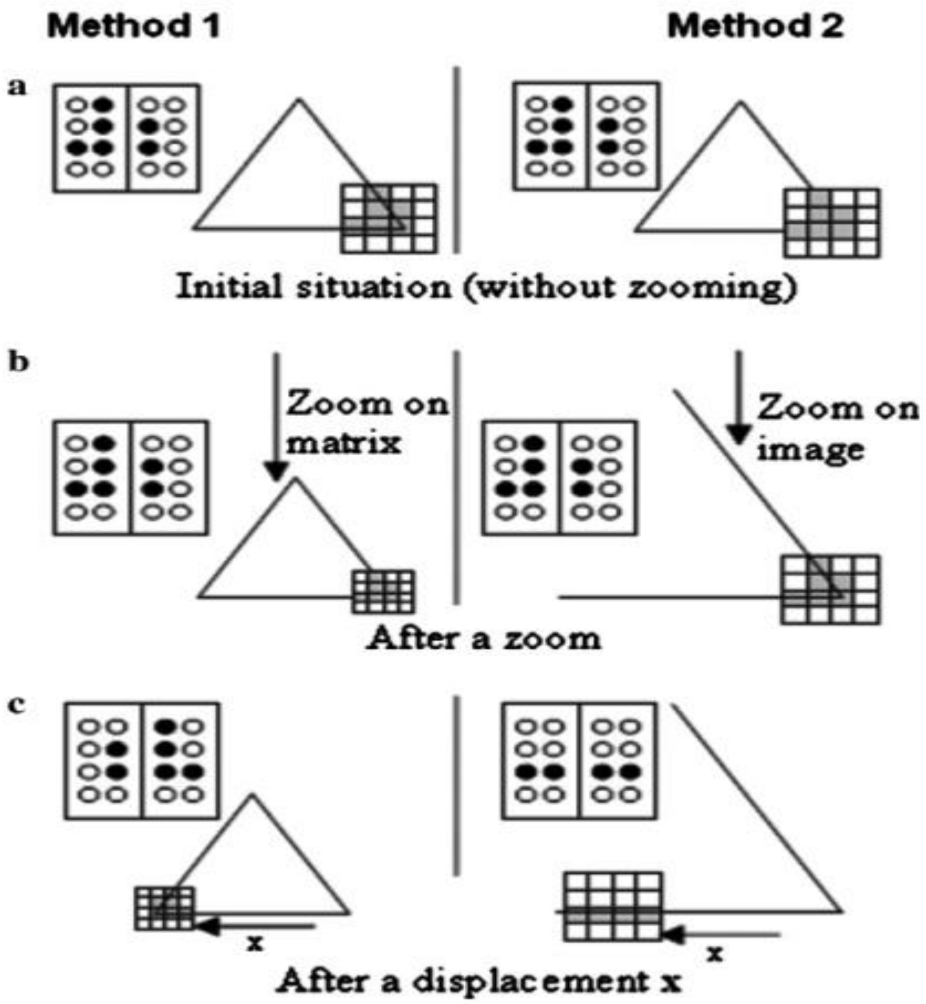


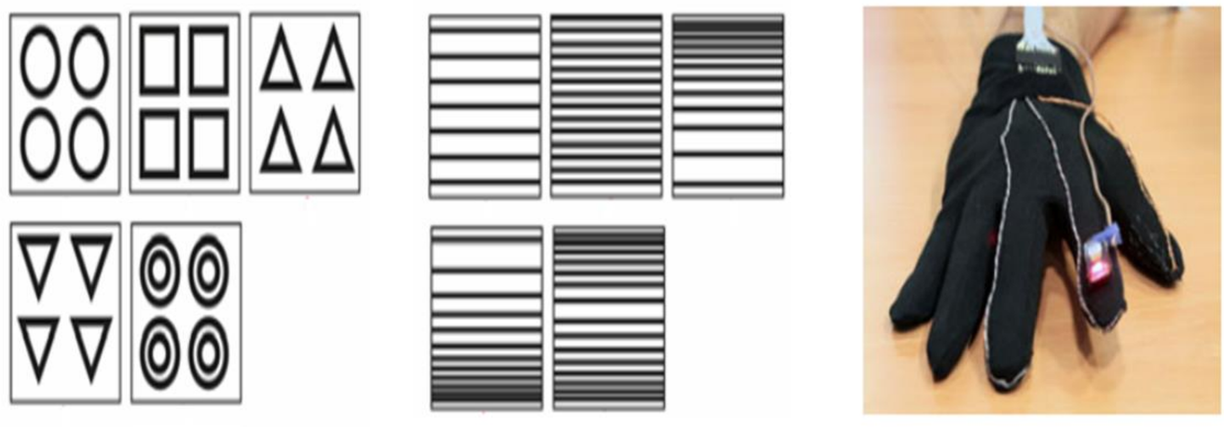
Figure 2.34 An example of applying the scaling methods [Ziat et al., 2007].

In figure 2.34, method 1 corresponds a reduction of the virtual cursor size, and method 2 corresponds an increasing in the dimensions of the rendered image. Figure 2.34(a) presents rendering figures without zooming. The part b of figure 2.34 presents the activated pins for the two methods. The activated pins are similar for the two methods. After a movement X by the subject, the activated pins are different in the two methods. Figure 2.34(c) presents this difference [Ziat et al., 2007].

Many researches have been conducted to study the effects of textures on perceiving the spatial graphics using tactile sensation [Hollins et al., 2002]. Studying the geometry of the texture elements includes elemental shape, size, density, spacing, arrangement, and orientation of texture elements [Hughes, 2006] [Hollins et al., 2002]. A research conducted by [Hollins et al., 2002] proved that fine tactile textures could be detected by vibro-tactile sensation. A series of experiments have been conducted by [Hughes, 2006] for studying the effects of orientation differences in adjacent segments of shape textures on the perceptual sensitivity of touch. The authors found that the sensitivity to the orientation differences was a function of [Hughes, 2006]:

- the reference orientation; and
- the magnitude of that difference.

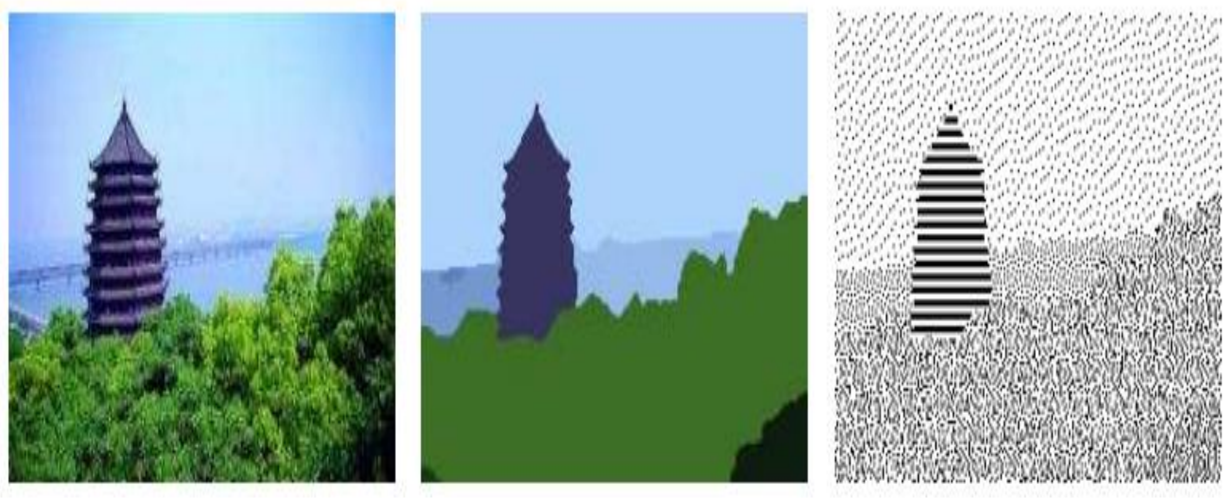
A series of experiments have been conducted by [Martínez et al., 2011] to compare the performance of visually impaired persons in recognizing different geometrical shapes with many texture types using force-feedback device, a custom-built vibro-tactile data-glove supported by a small vibrating actuator based on the index finger, and embossed paper sheets. Results showed that the performance of visually impaired persons using vibro-tactile data-glove is better in detecting the textures. Results showed that controlling the vibration by changing the frequency values of tactile stimuli is even useful to detect more complex textures [Martínez et al., 2011]. Figure 2.35 presents sets of forms and textures, and the data-glove used in these experiments [Martínez et al., 2011].



(a) (b) (c)

Figure 2.35 Groups of forms, textures, and the data-glove, (a) five geometrical shapes, (b) five types of textures, (c) the used data-glove [Martínez et al., 2011].

An approach for converting graphical information (and pictorial) into tactile patterns has been suggested by [Pappas et al., 2009]. The proposed approach segments a scene into uniform blocks, and generates many distinct tactile patterns, and maps the visual textures of the blocks into tactile textures. Figure 2.36 presents an example of visual to tactile mapping with many kinds of textures [Pappas et al., 2009]. The authors used the digital image halftoning techniques [Pappas et al., 2003] to generate automatically many types of tactile textures. Figure 2.37 views some examples of generated tactile textures [Pappas et al., 2003]. The authors conducted a series of subjective tests with sighted (but visually blocked) and visually impaired persons, and found that it is possible to generate perceptually distinguishable tactile patterns, and that different dimensions of tactile texture can be identified using the proposed approach.



(a) (b) (c)

Figure 2.36 Visual to tactile mapping (a) original image (b) segmented image (c) tactile display [Pappas et al., 2009].

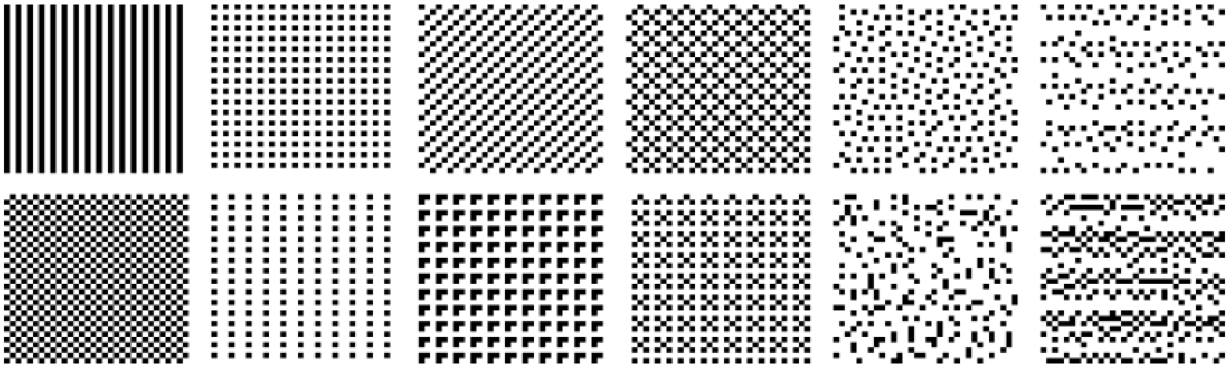
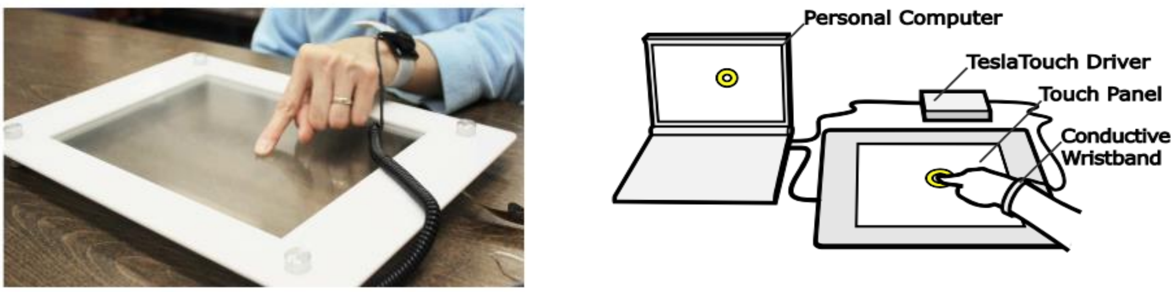


Figure 2.37 Different types of generated tactile textures [Pappas et al., 2009].

TeslaTouch, a touch sensitive screen with haptic feedback, has been used to develop some applications targeted to visually impaired persons in order to create and interpret two-dimensional tactile information [Xu et al., 2011]. Figure 2.38 represents TeslaTouch and the components of the designed system [Xu et al., 2011]. The authors conducted a series of experiments with visually impaired persons to evaluate their performance to identify many spatial shapes. The tested geometric shapes are circles, squares, and triangles. The width and height of each shape were 5 cm, they were rendered in three styles: outline, solid, and solid with outline. Figure 2.39 represents the three styles of a circle shape [Xu et al., 2011]. In Figure 2.39, changes in the darkness of the shape indicate changes in the intensity of the haptic signal, and the red lines indicate the finger exploration traces. The average percentage of correct identification was 56%. The best results were obtained for the solid rendering style, where the participants achieved about 80% of correct identification.



(a) (b)

Figure 2.38 TeslaTouch and the designed system, (a) TeslaTouch touch sensitive screen, (b) components of the designed system [Xu et al., 2011].

(a) (b) (c)

Figure 2.39 Three rendered styles of a circular shape, (a) outline, (b) solid, (c) solid with outline [Xu et al., 2011].

Many other researches have been conducted to evaluate the ability of visually impaired persons to recognize geometric shapes, such:

- the approach proposed by [Noble et al., 2006] that used VTPlayer mouse [Pietrzak et al., 2006] - a device with two braille displays- to teach visually impaired persons simple geometric shapes;
- SpaceSense: a handheld system to represent geographical information [Yatani et al., 2012];
- a multi-finger 2-D haptic display device that supports a parallel processing of haptic information [Burch et al., 2011].

To summarize the spatial-oriented tactile vision substitution systems: many systems have been designed to run on touch-screen mobile devices such GraVVITAS [Goncu et al., 2011], and TeslaTouch [Xu et al., 2011]. Some systems are oriented to be integrated with personal computers such Tactos [Hatwell et al., 2003]. Other systems use a specialized refreshable tactile device such MaskGen [Petit et al., 2008] [Levesque et al., 2008].

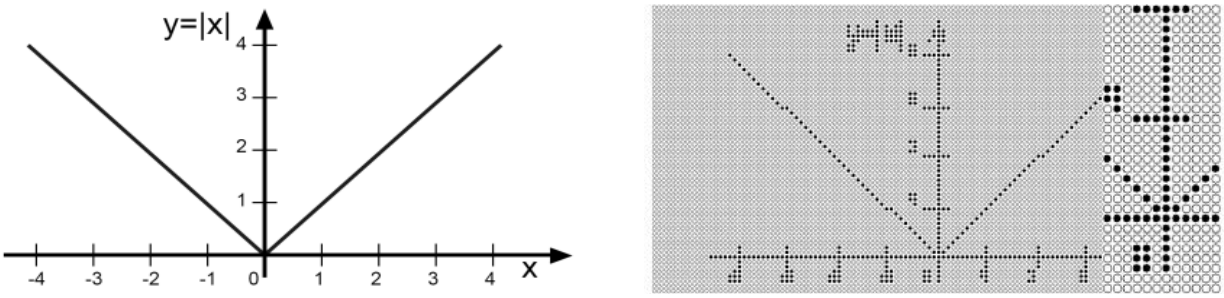
GraVVITAS [Goncu et al., 2011] has been designed to evaluate recognizing some complex 2-D objects such tables, floor plans and line graphs. But, it is not specialized for viewing web pages' structures. Considering that the web pages are more complex than the mentioned 2-D objects. The system proposed by [Pappas et al., 2009] segments a scene into uniform blocks, and it maps the visual textures of the blocks into tactile textures. This system does not support a special segmentation for the web pages' contents.

The previous proposed approaches are not specialized for treating information present in web pages. Next section views the approaches proposed to enhance the ability of blind persons to navigate the Web.

2.4 Non-Visual Web Navigating

Many researches tried to enhance the way by which visually impaired persons interact with web pages, such as [Alaeldin et al., 2011], that proposed a tactile web navigator to enable blind people to access the Internet. This navigator extracts texts from web pages, and sends them to braille coders using an array of solenoids [Alaeldin et al., 2011]. Some researches have been proposed to enable the visually impaired persons navigate the Web depending only on audio feedback, such as Webanywhere [Bigham et al., 2008], HearSay [Borodin et al., 2008], aiBrowser (Accessibility Internet Browser for Multimedia) [Miyashita et al., 2007], WebbIE [King et al., 2004], pwWebSpeak [De-Witt, 1998], Emacspeak [Raman, 2001], AB–Web [Roth et al., 1998], and WebSound [Petrucci et al., 2000].

A tactile web browser for hypertext documents (HTML and XHTML formats) has been proposed by [Rotard et al., 2005]. This browser renders texts and graphics present in web pages using a tactile graphics display consists of 120x60 pins (37x19 cm). The proposed system explores the web page images of types bitmap and scalable vector graphics (SVG), and applies filters on these types of images to reduce the density of visual information and to extract their important information. The extracted text is rendered on the tactile graphics display in 8-dot braille coding. Figure 2.40 shows an example image of a mathematical diagram encoded as scalable vector graphics format, and how it is represented on the tactile graphics display.



(a) (b)

Figure 2.40 Rendering a mathematical diagram into tactile output, (a) the original image, (b) the tactile rendered image [Rotard et al., 2005].

Another model called MAP-RDF ("Model of Architecture of web Pages") [BouIssa et al., 2009] proposed a method to improve the accessibility to visual information for blind persons. This model allows representing the structure of a web page, and provides the blind users with an overview of the web page layout and its structure semantics. This model was built basically on two previous models [BouIssa et al., 2009]:

- picture of the page model [Luc et al., 2000], and
- the textual architecture model [Virbel, 1985], [Virbel, 1989].

The model could be applied only on well-structured web pages which contain meta-data. It divides the HTML elements into two categories:

- basic visual objects: textual blocks, titles, hypertext links, images, and data input fields;
- group visual objects: menus, headings (title + image + textual block + link), front headings (group of images in front of the page), calendars, and forms.

The system transforms each one of the basic and group visual elements into graphical symbols as illustrated in figure 2.41. In figure 2.41, there are many symbols; each one represents an HTML element. For example, the symbol represents a menu of items; and the symbols and represent texts with cold and hot colors. The system provides two possibilities of outputs: oral (using Jaws screen reader speech synthesizer), tactile (graphical symbols and braille coding on tactile papers), or a combination of the two outputs [BouIssa et al., 2009].

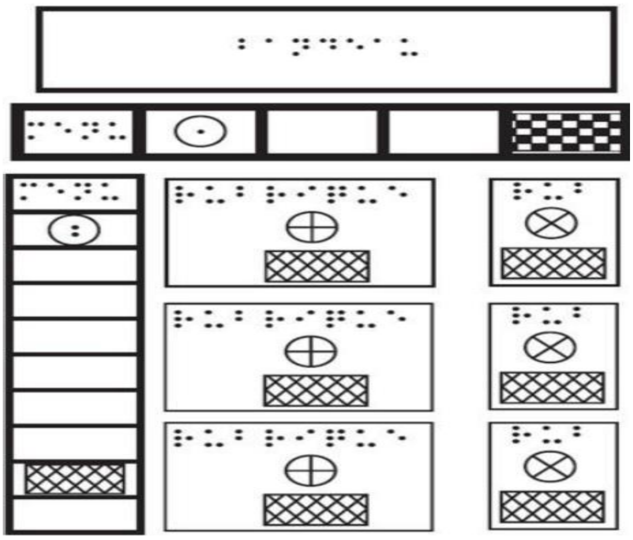


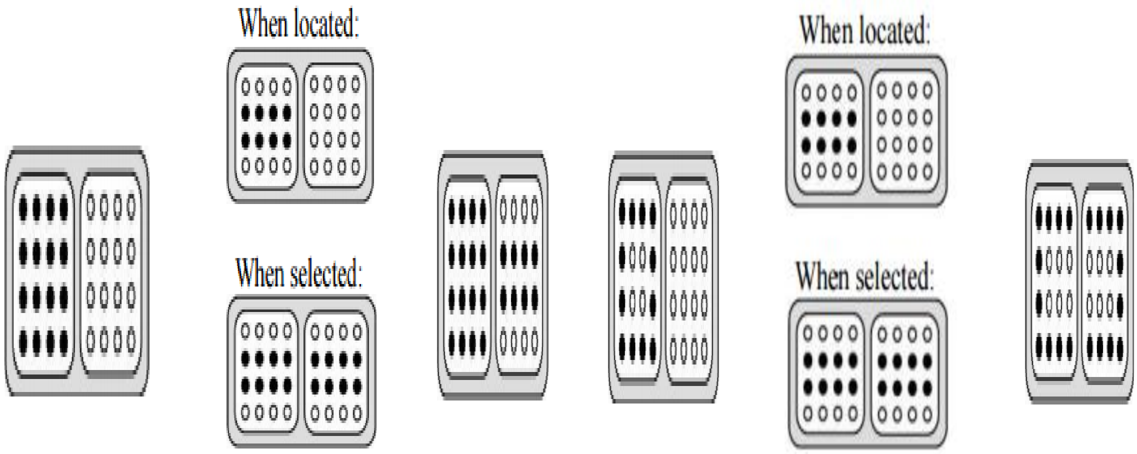
Figure 2.41 Symbols represent HTML elements in MAP-RDF approach [BouIssa et al., 2009].

A tactile web browser for blind users has been proposed by [Kuber et al., 2010]. The system enables blind persons to explore web pages using tactile feedbacks. A tactile mouse was used to communicate the presence of graphical interface objects. The tactile mouse contains two cells positioned on top of the mouse; each cell contains a matrix of sixteen pins. The pins can be raised to form tactile patterns, which are touched by the fingertips (cf. Figure 2.42) [Kuber et al., 2010]. The authors designed a support structure for the mouse which allows the mouse to be moved only along a slider both vertically and horizontally, enabling the user to maintain a straight path. The support structure is presented in figure 2.42 (b).

(a) (b)

Figure 2.42 A tactile mouse with a support structure, (a) the mouse with two cells positioned on top, (b) the support structure for the mouse [Kuber et al., 2010].

The authors proposed tactile patterns that map HTML elements (cf. figure 2.43) [Kuber et al., 2010].



(a) (b) (c) (d) (e) (f)

Figure 2.43 Tactile patterns (a) an image, (b) a hyperlink, (c) an image hyperlink, (d) a textbox, (e) a button, (f) a header [Kuber et al., 2010].

The authors have evaluated the system with five blind users aged between 20 and 68. Web pages were presented to participants. The presented web pages contain tactile HTML elements (tactile patterns). The participants were first asked to explore the interface using the tactile mouse, and then to describe the layout of the navigated pages. Some participants were able to perceive the global layout of some pages but with inconsistencies in mapping some elements such as inconsistencies between images and image-hyperlinks. The main problem encountered by participants was perceiving sizes of objects. It was difficult for some participants to suggest whether images were large or small comparing to the relative size of the page. Figure 2.44 views an example for a spatial representation of a web page drawn by a blind user.

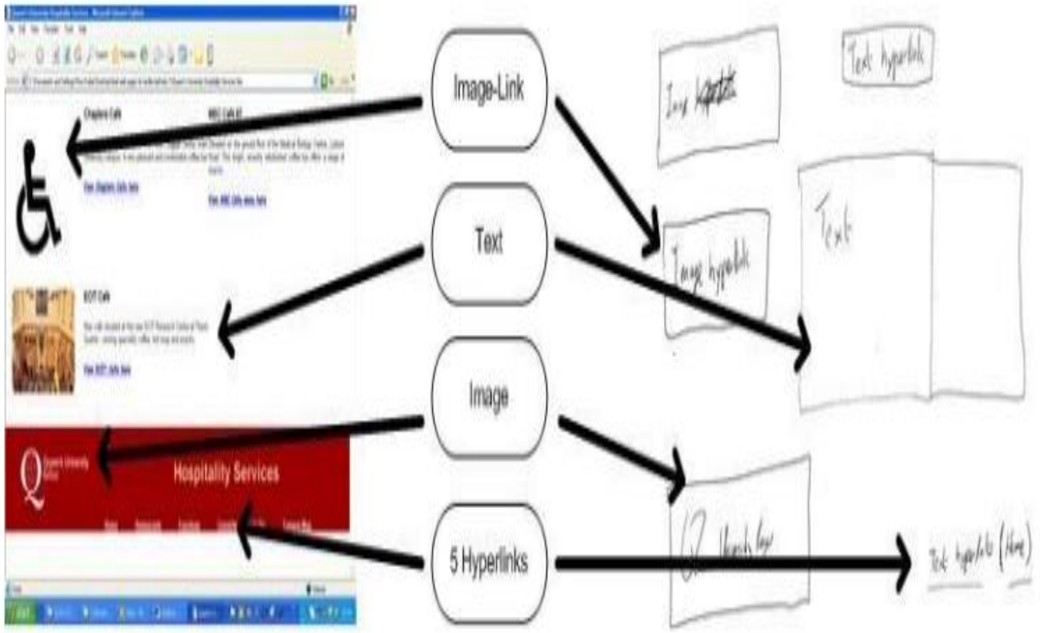


Figure 2.44 A spatial representation of a web page drawn by a blind user [Kuber et al., 2010].

Some approaches convert the textual content of web pages into braille format such:

- BrailleSurf [Hadjadj et al., 1999], an internet browser for visually impaired users. It converts the contents of a web page directly to braille coding. The system analyzes the HTML source code of a web page, and filters graphical objects and constructs a braille output that describes the content of the page [Hadjadj et al., 1999];
- BrailleSUM [Wan et al., 2015] presents a news summarization system for visually impaired persons. The system considers the factor of sentence lengths in news articles, and summarizes them as short as possible. Evaluating the system showed that BrailleSUM can produce shorter braille summaries than existing methods, and the system does not sacrifice the content quality of the summaries [Wan et al., 2015].

CSurf [Mahmud et al., 2007] addresses the problem of information overload in non-visual web access focusing on the topic context and on filtering a lot of irrelevant data. When a user follows a link, the system captures the context of the link using topic-boundary detection techniques (using the words of the link), and uses it to identify relevant information in the next web page. Then, CSurf reads the next web page starting from the most relevant section [Mahmud et al., 2007]. The system uses many advanced techniques in content analysis, natural language processing (NLP), and machine learning algorithms to achieve this solution. The authors evaluated the performance of CSurf against the state-of-the-art screen-reader JAWS [Freedomscientific, 2016]. Results showed that the use of context can improve browsing experience of visually impaired people and potentially save browsing time [Mahmud et al., 2007]. The authors did not mention how the system deals with links that contain only symbols and numbers, or how the system deals with links included in buttons or images.
TactoWeb is a multimodal web navigator that provides visually impaired persons with a spatial navigation of web pages using tactile and audio feedback [Petit et al., 2011]. TactoWeb depends on a

lateral device to produce a tactile feedback [Levesque et al., 2008] [Hayward et al., 2000] (details of this device is explained in chapter 1, section 1.10). This lateral device consists of a tactile cell (8 x 8 actuators distributed on 9 x 11 mm) that stimulates the tip of the finger by laterally stretching and contracting the skin [Petit et al., 2011] [Levesque et al., 2008]. The actuators move from right to left in order to produce tactile sensations like vibration. Figures 2.45 and 2.46 present, respectively, the Tactograph device and a prototype of the used tactile cell [Petit et al., 2011].

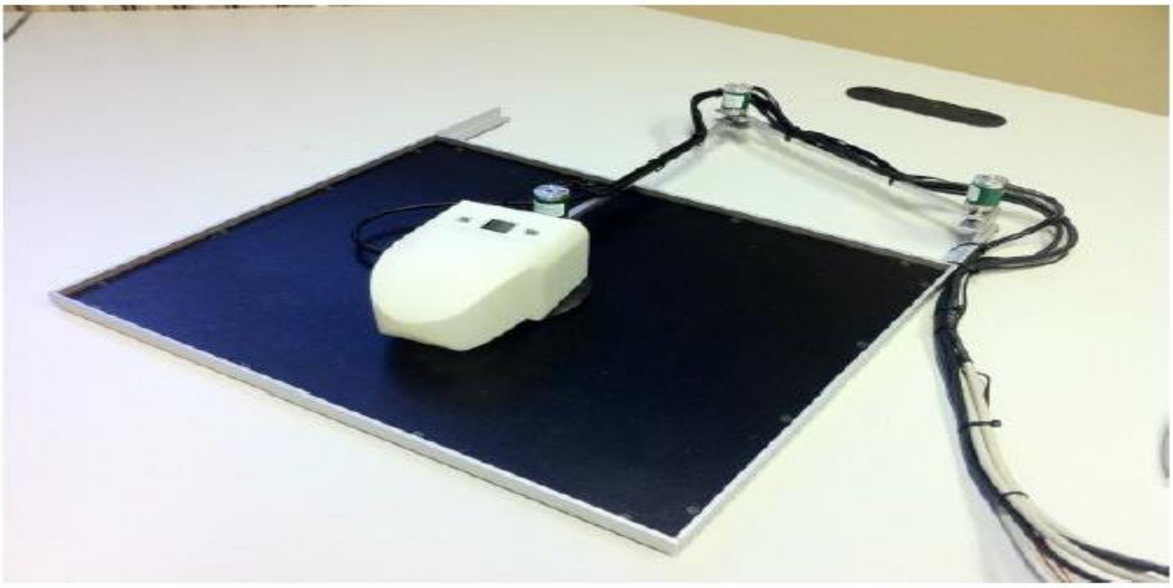


Figure 2.45 Tactograph device [Petit et al., 2011].

Figure 2.46 A prototype of a tactile cell used TactoWeb [Petit et al., 2011].

TactoWeb analyses the DOM tree of a web page and adapts some web page elements (headers, links, paragraphs, menus, numbered lists, images, buttons, and form elements) to tactile format. Each of these elements has a specific tactile feedback. Figure 2.47 views an example of rendering a web page using TactoWeb [Petit et al., 2011]. TactoWeb preserves the positions and the dimensions of original web page HTML elements while the process of rendering. The authors use many types of textures (details of these textures are explained in chapter 1, section 1.10). Unfortunately, the authors did not conduct any experiment with visually impaired persons to evaluate their ability to perceive web page layouts TactoWeb.

Figure 2.47 An example of rendering a web page using TactoWeb [Petit et al., 2011].

Some types of force feedback devices have been used in designing approaches for non-visual web navigation. PHANToM desktop force feedback haptic device [Massie et al., 1994] has been used in many applications targeted to visually impaired persons, either to access 3D objects included in web pages [Magnusson et al., 2006], or to access a virtual 3D scenes represent web pages [Kaklanis et al., 2009] [Nikolakis et al., 2004]. Wingman Mouse (1.9 x 2.5 cm) [Wingman, 1999] is another example of force feedback devices. It was used in designing some approaches to access graphical objects (such as maps) included in web pages [Baptiste-Jessel et al., 2004]. A multimodal approach for mapping a web page to a 3D virtual reality environment enriched with audio and haptic feedbacks has been proposed by [Kaklanis et al., 2009]. This approach transforms each web page HTML element into a 3D object that contains haptic information ("hapget"). Collecting these hapgets together formulates a 3D virtual scene. The position (X, Y, and Z) of each hapget is relative to the 2-D position of the corresponding HTML component in the original web page. The proposed 3D haptic browser views the contents of a web page in a 3D form, and it supports a haptic feedback when the user interacts with hapgets using a PHANToM desktop haptic device. Figure 2.48 views an example of corresponding HTML components to hapgets [Kaklanis et al., 2009]. The authors evaluated the proposed approach. The main drawback is that visually impaired persons easily lose the position and the direction during navigating the 3D tactile web page [Kaklanis et al., 2009].

Figure 2.48 An example for corresponding HTML components to hapgets (rendering of web page http://www.hcii2009.org) [Kaklanis et al., 2009].

A haptic-gloves prototype has been proposed for audio-tactile web browsing [Soviak et al., 2015, a] [Soviak et al., 2015, b]. The system (called FeelX) provides visually impaired persons with a tactile feel of the 2-D layout of web pages. The system is composed of following components:

- a camera located over a flat surface such as a desk or a table,
- a finger tracker,
- a controller,
- haptic gloves, and
- an interface manager.

A haptic hardware unit is located on each glove finger. This unit controls a tactile matrix of 2x4 cells. Figure 2.49 presents these components [Soviak et al., 2015, a].

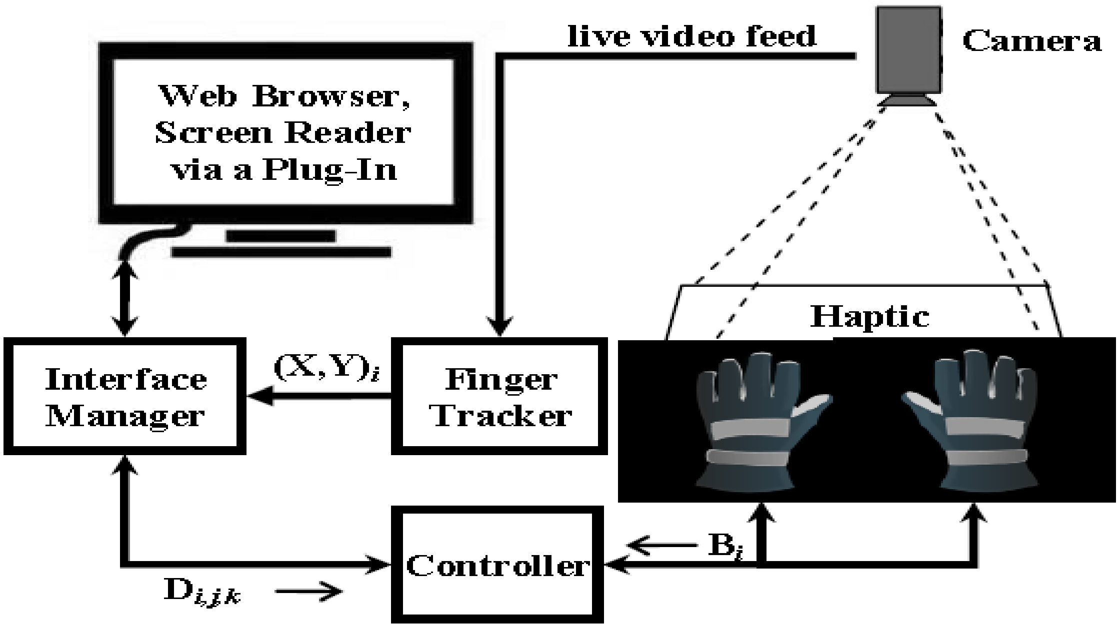


Figure 2.49 Components of haptic system FeelX [Soviak et al., 2015, a].

The camera is fixed over a flat surface, and sends live video feeds of the gloves to the finger tracker. A standard computer vision algorithm is used by the finger tracker to resolve the (X,Y) coordinates for each finger, and sends these coordinates to the interface manager. The interface manager interacts with standard screen readers and web browsers via a browser plug-in component. The interface manager (via the browser plug-in) obtains the web page content and maps the (X,Y) coordinates of finger i to the browser screen coordinates [Soviak et al., 2015, a] [Soviak et al., 2015, b]. Haptic feedbacks are sent via the controller to the haptic gloves to perceive a haptic sensation of simple shapes, such as lines and boxes [Soviak et al., 2015, a]. The authors did not document any evaluation results for this system.

To summarize the presented systems that are oriented to non-visual web navigating: some systems extract the texts of a web page and send them to braille coders such BrailleSurf [Hadjadj et al., 1999], BrailleSUM [Wan et al., 2015], and the system proposed by [Alaeldin et al., 2011]. Other systems are more oriented to hypertext documents, such that system proposed by [Rotard et al., 2005]. This system presents texts and graphics present in web pages. But, it does not support information about the global 2-D spatial structure of a web page.

2.5. Conclusion of Chapter 2

Studying perceiving the basic shapes and textures by visually impaired persons is a preliminary step for studying their ability to perceive the structures, and the spatial layouts of digital documents, especially the layout of web pages. This chapter presented main proposed approaches to design vision substitution systems that aim to present visual information either in tactile or in audio format, or in the two formats together. Evaluation results of these presented works conclude that it is possible for visually impaired persons to perceive basic types of complex geometric shapes, but this requires supporting them by vision substitution systems that take into account their perceptual capabilities of tactile and audio receptors, and their ergonomic aspects.

The chapter discussed many different approaches of tactile vision substitution systems. The Braille-coding oriented tactile vision substitution systems depend principally on the Braille coding, and this causes a difficulty for blind persons that do not know the Braille coding. Especially that the percentage of blind persons who do not know Braille coding is very big. For example, in France, less than 1% of visually impaired persons use machines specialized for producing and dealing with Braille texts [Enquête HID, 2005]. The majority of viewed Braille-coding oriented systems do not transfer the spatial features for the global structure of the presented document. Braille window system [Prescher et al., 2010] presents an overview of the viewed document by presenting its content as abstract rectangles. But, it requires a special planar tactile display. The mentioned system is not portable. The system supports only Microsoft Windows systems. In addition, it does not present any support for presenting Web pages.

Some vibration-oriented tactile vision substitution systems are oriented only to read textual contents without supporting any spatial information about the global structure of the viewed document, such D.E.L.T.A. "Dispositif Electronique de Lecture de Texte pour Aveugles" [Conter et al., 1986]. The majority of presented vibration-oriented systems have been designed to present basic shapes such rectangles, circles, triangles, etc.; and they have not been designed to view complicated structures such web pages. STIMTAC [Amberg et al., 2011] displays the texture by creating an air bearing between the user finger and the device surface, but it is not targeted to view the different textures in web pages' segments.

Some spatial-oriented tactile vision substitution systems have been designed to evaluate recognizing some complex two dimensional objects such tables, floor plans and line graphs. But, they are not specialized for viewing web pages' structures. Considering that web pages are more complex than the mentioned two dimensional objects. Other presented systems segment a scene into uniform blocs and map the visual textures of the blocks into tactile texture. This type of systems does not support a special segmentation for the web pages' contents.

The majority of presented systems that are oriented to non-visual web navigating focus on extracting the texts in web pages more than presenting the global structures of the page. The model MAP-RDF "Model of Architecture of web Pages" [BouIssa et al., 2009] represents the structure of a web page. But, this model could be applied only on well-structured web pages which contain meta-data. In addition, this model is oriented to tactile papers, and it is not adaptable to touch-screen mobile devices.

Some systems present a global overview of a web page such the TactoWeb [Petit et al., 2011], and the tactile web browser for blind users proposed by [Kuber et al., 2010]. But, these two systems are oriented to be integrated with personal computers, and they are not adaptable to touch-screen mobile devices. The majority of proposed systems map the HTML elements to tactile symbols (element by element) without trying grouping the HTML elements in segments, and this makes skimming the web pages more difficult for the visually impaired persons.

To conclude, some TVSS are not portable. The majority of TVSS does not present the web pages' structures; especially that perceiving the layout of a document is often indispensable to understand its contents [Francisco-Revilla et al., 2009]. Many studies confirmed the importance of the structure, the layout, and the spatial cues of web pages in enabling many tasks, and in guiding the reader to analyze and to find data items [Yesilada et al., 2004]. Some proposed solutions map directly the HTML elements to tactile symbols without trying grouping them in segments, and this is different of the natural way of skimming web pages. Grouping the related elements helps the user in dealing with complex information by reducing it to a manageable number of units, and to orient quickly his/her attention to interesting parts in a systematic and predictable manner [Hornof et al., 2001].

To overcome some mentioned inconveniences, a new portable web-oriented tactile vision substitution system has been designed. Next part discusses the designed system which is more portable than current tactile vision substitution systems. In addition, it supports the visually impaired persons by a new method to navigate the web pages. Portability, low cost, usability, lightness, noiseless, integrating with touch-screen mobile devices, ignoring Braille coding; and running in real-time, are the most important features of the designed systems. All these features are discussed in details in next part.

Part 2:

System Description
Hardware and Software implementation
Basic Parameters and Arguments of the Graphical Vibro-tactile Language

Navigating the Web is time-consuming for visually impaired persons comparing with sighted persons due to the limitations of current assistive technologies while navigating the Web. Enhancing the mobile web accessibility is a main objective for many researches and studies. One axis of researches in mobile web accessibility is enhancing the non-visual navigation of web pages on touch-screen mobile devices. Perceiving the web page layout enhances the human non-visual interaction with web pages [Murphy et al., 2008], and it enhances the exploration process and navigation strategies for visually impaired web users [Murphy et al., 2008] [Yu et al., 2005].

This part discusses the main objective of our designed tactile vision sensory substitution system TactiNET, and some technical details of the proposed solution. This part starts first by discussing the objective and the hypothesis of designing the proposed system. Then, the global schema of the system and the methodology to achieve the proposed solution are presented. This part consists in three chapters. The first chapter is entitled "hardware implementation". It presents the criteria, conditions, and properties desired to be in the implemented hardware components of TactiNET, and the two designed devices that were produced during this work. The second chapter is entitled "software implementation". It presents the main software components and resources used to construct TactiNET software. The third chapter presents three experiments that have been executed to select a series of values, and arguments that are fundamental for designing the graphical vibro-tactile language.

The objective, the research question, and the hypothesis

This PhD subject is a part of the project ART-ADN ("Accès par retour tactile-oral aux documents numériques") [ANR-ART-ADN, 2013] [ART-ADN, 2013] sponsored by the national agency of research in France [ANR, 2016]. The project is accomplished by the laboratory GREYC (Groupe de Recherche en Informatique, Image, Automatique et Instrumentation de Caen) in university of Caen Normandy [GREYC-Unicaen, 2016], and the laboratory PALM (Le laboratoire Psychologie des Actions Langagières et Motrices) in university of Caen Normandy [PALM-Unicaen, 2016], in collaboration with the company SemioTime [Semiotime, 2016], and the association Cécitix [Cécitix, 2016].

The project ART-ADN aims to study, develop, implement and evaluate innovative features of non-visual access to the web pages. The project ART-ADN focuses on two modalities for non-visual access: tactile modality (more precisely: vibro-tactile), and oral modality. The tactile modality is more oriented to replace the skimming techniques, while the oral modality is more oriented to replace the scanning techniques during navigating the web pages. Skimming techniques are used by sighted persons to get a global overview of the content structure, and to perceive quickly the document layout and its structural semantics [Maurel et al., 2012] [Ahmed et al. 2012]. Scanning techniques allow the user to look for a specific piece of information following various reading paths [Francisco-Revilla et al., 2009] [Ahmed et al. 2012].

This work aims to improve the navigation method of blind people within web pages displayed on touch-screen mobile devices by focusing on the tactile modality. To achieve this objective, a tactile vision sensory substitution system (TVSS) TactiNET has been realized. This TVSS system has been used to execute many experiments with sighted and blind persons. All these experiments have been executed in order to answer the following research question "*what are the effects of* ***Vibro-tactile feedbacks*** *on the ability of visually impaired people to* ***perceive web pages layouts*** *browsed on* ***touch-screen mobile devices"***. In this research question sentence, there are three important points:

- the Vibro-tactile feedbacks;
- perceiving web pages layouts;
- using touch-screen mobile devices.

Vibro-tactile feedback is a way to generate a tactile perception by using vibrating actuators; and by controlling many parameters of the actuators such as frequency, amplitude, location, waveform, and duration. A web page layout is an arrangement of visual elements, so that related items are physically grouped together (in case they are adjacent), in order to guide the user to the information he/she needs [Hornof et al., 2001]. In the proposed solution, the focus was on perceiving web pages layouts because of their importance to understand the web pages contents [Maurel et al., 2012] [Francisco-Revilla et al., 2009] [Yesilada et al., 2004], and their effects in enabling many tasks, and in guiding the reader to analyze and to find data items [Yesilada et al., 2004].

In current proposed solutions, touch-screen mobile devices are the chosen means to be used for navigating the Web. This option has been chosen because of their importance in daily living activities, and they are the primary form of accessing the Web in many parts of the world [Harper et al., 2014]. This option increases the complexity of the proposed solution, because of their small-sized screens, and their limited input capabilities.

The proposed idea to achieve this objective is converting automatically the visual structures that represent the layout of a web page into a vibrating page. The vibrating page will be represented on a touch-screen device using a graphical vibro-tactile language. A graphical vibro-tactile language will be defined as a set of rules, principles, and recommendations for managing a non-visual interaction between the user and the navigated vibrating page. These rules and principles will be presented in next chapters. A vibrating page is a transformed format of a normal web page. It contains graphical geometrical symbols (forms) dedicated with vibro-tactile feedbacks. The vibro-tactile feedbacks are based on transforming the light contrasts into tactile vibrations. Figure 3.1 presents an example of a simple Graphical Vibro-Tactile Language (GVTL). The main basic graphical elements are geometrical forms, such polygons 1, 2, 3, 4, 5, and 6 in figure 3.1. These geometrical forms have different sizes (surfaces), lengths, widths, locations, and different spatial relations. A particular vibro-tactile feedback is dedicated for each shape. These vibro-tactile feedbacks could be varied in frequency, amplitude, waveform, and duration, such feedback signals 7, 8, 9, 10, 11, and 12 in figure 3.1. This simple GVTL could be used to represent a web page. Shapes may represent segments of HTML elements (paragraphs, images, other parts in a web page). Varieties in semantic meanings between the segments contents can be represented by different types of vibration.

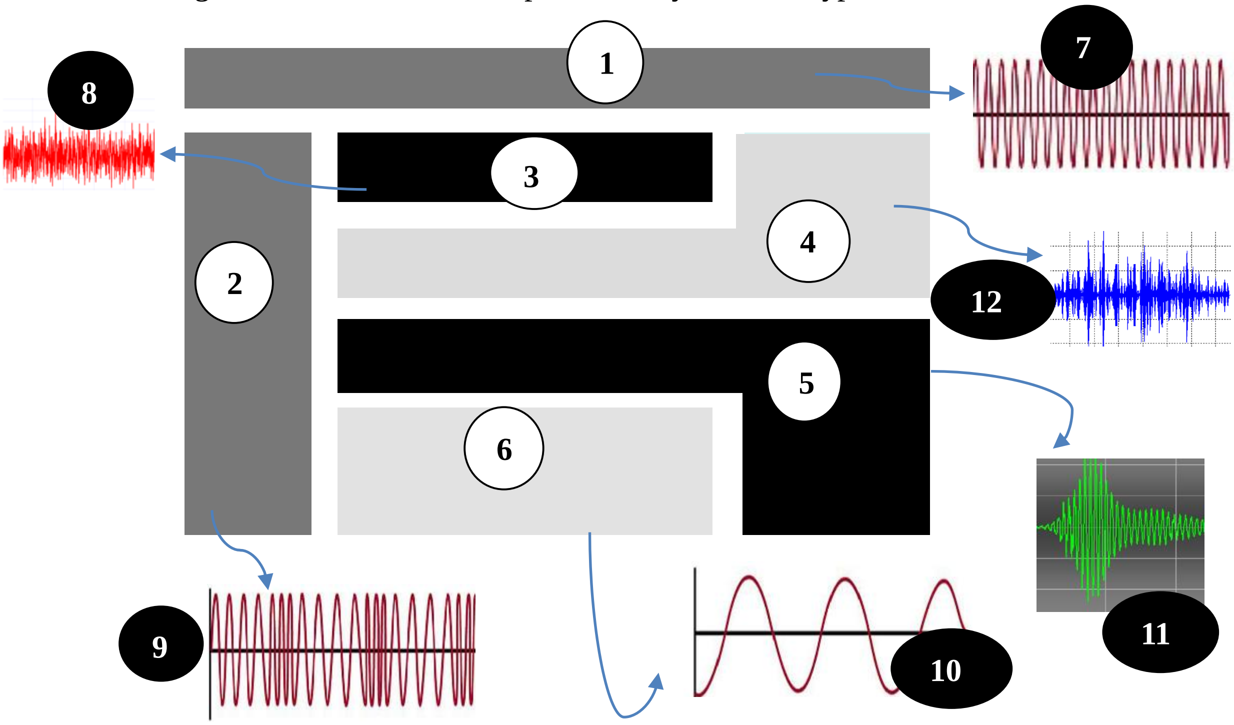


Figure 3.1 An example of a simple graphical vibro-tactile language.

The proposed idea is based on a hypothesis that visually impaired persons can explore graphical geometrical shapes on a touch-screen mobile device, and they can perceive their varieties in size, form, spatial relations, and semantic contents by using vibro-tactile feedbacks. Next section will discuss the proposed methodology to achieve this idea.

This proposed idea could be considered as a new non-visual navigation solution for exploiting the spatial two-dimension information of web pages interfaces. This navigation approach may be equivalent to classical visual exploration of a document based on a luminosity vibration. In other words, the visual information presented on digital screens obtained by the visual scanning methods, may be obtained by a manual exploration strategy based on vibro-tactile interaction.

Methodology

Converting a web page into a vibrating one can be imagined as a process of translating a message from a language to another one. In a translation process, three points should be taken into account:

1. the source language nature,
2. the destination language nature,
3. the translation techniques to guarantee an optimal transformation of meaning depending on the context, and to avoid losing information.

In the same way, in the converting process of web pages from a visual form to a tactile form, three points should be taken into account:

1. the properties of source visual web pages,
2. the properties of destination tactile web pages,
3. the conversion techniques from visual web pages to vibrating pages.

For each of the three indicated points, many questions should be taken into account to propose a successful converting methodology.

Concerning the properties of source visual web pages to be converted into vibrating forms:

- what are the categories of these web pages (sport, e-commerce, medical, news, etc.)?
- what are their accessibility and technological properties?
- conversion from visual form to tactile form should be achieved "element by element" (html element to a tactile symbol), or "segment to element" (converting a group of similar HTML elements to a tactile symbol)? (here, a segment in a web page means a part of a web page that contains a group of HTML elements such paragraphs, images, etc..).

Concerning the properties of destination vibrating web pages:

- what are the forms that visually impaired persons can perceive?
- how to locate and to conserve the converted forms on a touch-screen mobile device (dimensions, sizes, orientation, spatial relations)?
- what are the parameters of vibration signals that could be controlled (frequency, amplitude, waveform, and duration)?

Concerning techniques of converting from visual web pages to vibrating web pages:

- what are the minimum values of geometrical forms properties that visually impaired persons can perceive (minimum length of a shape edge, minimum distance between two shapes, etc.)?
- what are the ranges of values of vibration signals that visually impaired persons can perceive (range of frequency values, range of amplitude values, etc.)?
- how to represent the semantic meaning of web pages segments as vibration signals?
- what are the web pages on which the suggested conversion techniques will be evaluated?

Depending on the previous proposed questions, and the possible answers for each one, the following global steps have been proposed to achieve the desired conversion:

1. extraction and re-organization the visual elements in a web page, and grouping the similar elements in segments,
2. plotting the constructed segments on a touch-screen mobile device,
3. converting automatically the semantic meaning of each segment into a vibrating form.

The first step aims to extract the web page layout, and to reduce and simplify the density of visual information. Many studies confirmed that extracting semantic information and reformatting web pages can enhance levels of accessibility [Murphy et al., 2008] [Hollins et al., 2002]. Some studies recommended reducing and simplifying the pieces of visual information when converting them to tactile format, in order to accommodate the lower acuity of the touch sense [Levesque et al., 2008]. Other studies confirmed that identical spatial mapping of information from vision to tactile is not valid [Hollins et al., 2002] [Pappas et al., 2009], because the human tactile perception is very different from the human visual perception [Pappas et al., 2009], and because the limited spatial resolution of the tactile sense comparing with the vision sense [Pappas et al., 2009] [Palani et al., 2014]. In the proposed solution, extraction the visual elements in a web page depends on a vision-based approach. This vision-based approach first renders the web page and extracts the visual properties of its HTML elements. Re-organizing and filtering the visual elements depends on mining the DOM (Document Object Model), and applying many filters and re-organization rules to it. Grouping the filtered visual elements is achieved by an agglomerative graph-based clustering algorithm. Applying this algorithm on the filtered elements converts the web page into a set of related segments; each segment contains similar HTML elements. These three phases are detailed in chapter 4.

Representing the constructed segments on a touch-screen mobile device is constrained by many rules and criteria:

- rules for types of forms that could be perceived by visually impaired persons. All the forms are represented as rectangles. This option has been chosen after running an empirical experiment with sighted persons to understand how they segment web pages. And with blind persons to examine their performance in recognizing shapes through a vibro-tactile feedback. These two experiments are detailed in chapters 4 and 5.
- rules for the locations of forms represented on a touch-screen device (sizes, orientation, spatial relations). These rules have been chosen from the current state of the art for vibro-tactile perception on hand-held devices. Details of these rules are in chapter 6.
- rules for the parameters of vibration signals. Many parameters could be controlled to generate different vibration signals such as frequency, amplitude, waveform, and duration. The designed device TactiNET can control independently the frequency and the amplitude of the used actuators. So all the graphical forms in a normal web page will be represented in vibration mode by controlling frequency and amplitude parameters. Details of the hardware components of TactiNET are presented in chapter 3.

Converting the semantic meaning of each segment into a vibrating form depends on what are the pieces of information to be extracted from each segment, and how to transfer these pieces of information into frequency and amplitude values. A series of empirical experiments have been run to select the ranges of values of frequency and amplitude that visually impaired persons can distinguish. These experiments are detailed in chapter 5.

Extracting and representing the semantic meaning of contents for each segment is a critical point in the designed approach. After a series of experiments and evaluations to design an approach for extracting and representing the semantic meaning of segments; each segment has been represented depending on the contrast of its visual elements. Standard deviation is the chosen measure to represent the contrast of visual elements in each segment. This option has been chosen depending on the current state of the art for measuring the contrast in images. These values of standard deviation are essential to generate the values of frequency and amplitude of the vibro-tactile feedbacks. Details of using the standard deviation measure, and how to generate the values of frequency and amplitude dedicated for each segment are presented in chapter 6. Figure 3.2 presents the global hierarchy of the proposed system.

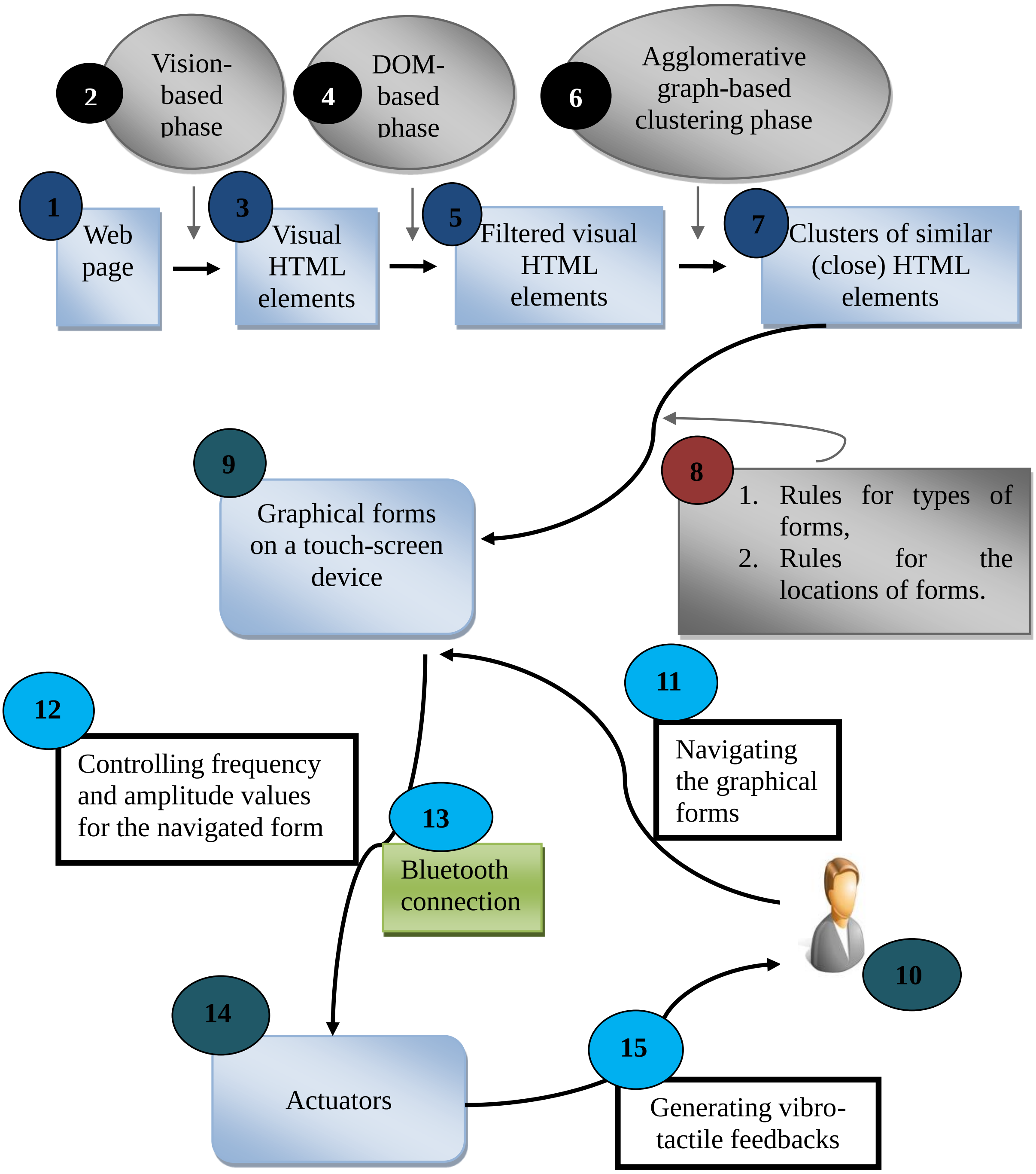


Figure 3.2 The hierarchy of the proposed system TactiNET.

In figure 3.2, the oval shapes with numbers 2, 4, and 6 represent three phases of the proposed graph-based clustering algorithm. These phases are:

- vision-based phase (oval shape number 2) that renders the web page and extracts the visual properties of its HTML elements. Its input is a web page (rectangular shape number 1), and its output is a set of visual HTML elements (rectangular shape number 3).
- DOM-base phase (oval shape number 4) that reorganizes and filters the visual elements by

mining the web page DOM structure. Its input is the extracted set of visual HTML elements (rectangular shape number 3), and its output is a filtered set of visual HTML elements (rectangular shape number 5).
- an agglomerative graph-based clustering phase (oval shape number 6) that groups the filtered visual elements by applying an agglomerative graph-based clustering algorithm. Its input is a filtered set of visual HTML elements (rectangular shape number 5), and its output is a set of clusters of similar HTML elements (rectangular shape number 7).

A set of rules for types of forms, and for the locations of forms (rectangular shape number 8) are applied to plot graphical forms on the touch-screen device (rectangular shape number 9). The plotted forms represent the web page structure.

A coupling of "interaction/vibro-tactile feedbacks" is activated by the system and the subject. The subject (element number 10) navigates the plotted forms. The system responds to this navigation process (rectangular shape number 11) by generating a series of vibration feedbacks (shape number 12). This response is generated by controlling the actuators (rectangular shape number 14) via a bluetooth connection (rectangular shape number 13).

The coupling of "interaction/vibro-tactile feedbacks" is consistent with the theory of action-perception coupling presented in chapter 1 section 1.10. The action corresponds a non-visual exploration on the touched-screen device. The perception corresponds understanding, recognition, and discrimination the information present on the touched-screen (forms, sizes, spatial relationships, textures, etc.). Hands are the used organs to achieve the actions of this action-perception coupling and to receive the generated vibration. This type of touch is active, where the hands and arms are always moving and exploring.

In figure 3.2, the colors and the types of forms have been chosen depending on following considerations:

- the numbers of shapes represent the temporal sequence of the coupling "interaction/vibro-tactile feedbacks" activated by the subject and the system;
- the oval shapes (such those of numbers 2, 4, and 6) represent phases or algorithms to be applied on a web page elements;
- the blue non-rounded rectangles (such those of numbers 1, 3, 5, and 7) represent either an input or an output for a phase, a process, or for an algorithm;
- the blue rounded rectangles represent hardware components of the system, such the blue rounded rectangle with shape number 9 that represents the touch-screen device, and the blue rounded rectangle with shape number 14 that represents the actuators;
- the gray non-rounded rectangle (with number 8) represents a set of rules and criteria;
- the black non-rounded rectangles (such those of numbers 11, 12, and 15) represent as of actions generated by the subject or responses generated by the systems.

An important research question in mobile web accessibility is designing a tactile vision sensory substitution system that enhances the non-visual navigation of web pages for visually impaired persons. In the previous sections, a global overview of the proposed system TactiNET, the objective, and the hypothesis have been introduced. Some technical details of the designed components have been presented. The designed hardware and software components, the details and the results of each experiment will be presented in next chapters.

Chapter 3:

TactiNET Framework Hardware Implementation

Résumé : TactiNET est un système de substitution sensorielle visuo-tactile (TVSS) qui vise à améliorer l'accès non-visuel vibro-tactile aux pages web sur les appareils avec un écran tactile, basé sur la conversion automatique des structures visuelles des pages Web en pages vibrantes. Pour atteindre cet objectif, les composants logiciels et matériels ont été mis en œuvre et conçus. Les composants logiciels sont chargés de convertir automatiquement les structures visuelles des pages Web en pages vibrantes, tandis que les composants matériels sont responsables de la génération de vibrations qui représentent la signification sémantique des segments des pages Web.

Ce chapitre commence par définir les critères, conditions et propriétés souhaités pour fabriquer les composants matériels de TactiNET. Deux appareils ont été produits au cours de ce travail. Le premier était une sorte de prototype avec quelques limitations concernant les actionneurs. Tandis que le second était un outil plus professionnel sans limitations concernant ses actionneurs. De plus, il est facile d'être contrôlé par une interface dédiée aux expériences psychologiques.

Le premier prototype de dispositif a été utilisé dans une expérience avec des personnes voyantes et aveugles. L'objectif de cette expérience était de valider l'hypothèse de base selon laquelle les aveugles sont capables de percevoir des formes géométriques de base présentées en mode vibro-tactile. Le deuxième prototype de dispositif a été utilisé dans trois expériences plus avancées avec personnes voyantes et aveugles. Les objectifs de ces trois expériences étaient d'explorer les meilleures configurations et paramètres pour générer des pages vibrantes et d'évaluer la performance des personnes malvoyantes à percevoir les mises en forme des pages vibrantes.

3.1 Introduction of Chapter 3

TactiNET is a tactile vision sensory substitution system (TVSS) aims to improve non-visual vibro-tactile access to web pages on touch-screen devices, based on converting automatically visual structures of web pages into vibrating pages. To achieve this objective, software and hardware components have been implemented and designed. Software components are responsible of converting automatically the visual structures of web pages into vibrating pages, while hardware components are responsible of generating low-frequency vibrations that represent semantic meaning of web pages segments. In this chapter, the focus will be on the hardware technical properties of TactiNET framework, while chapter 4 will discuss more the details of resources and software components.

This chapter starts first by defining criteria, conditions, and properties desired to be in the implemented hardware components of TactiNET. Two devices were produced during this work. The first one was a kind of prototype with some limitations regarding the actuators; while the second one was more professional tool with no limitations in its actuators. In addition, that it is easy to be controlled by an interface dedicated to psychological experiments.

The first prototype device has been used in one experiment with sighted and blind persons. The objective of this experiment was to validate the basic hypothesis that blind persons are able to perceive basic geometrical forms presented in vibrating mode. The second prototype device was used in three more advanced experiments with sighted and blind persons. The objectives of these three experiments were to explore the best configurations and parameters to generate vibrating pages and to evaluate the performance of visually impaired persons to perceive the layouts of vibrating pages.

3.2 Properties of the desired device to be integrated in TactiNET

As indicated in the first two chapters in part one, there were a lot of proposed solutions for visual impaired persons. But, there are some drawbacks for these proposed solutions. Some of proposed solutions are costly. Some of them depend on Braille techniques, where only few numbers of visually impaired persons have learned Braille coding [Maurel et al., 2012] [Webaim, 2016] [Screenreadersurvey2, 2009]. Some solutions are not suitable for mobile devices [Maurel et al., 2012]. Other solutions are not efficient in noisy and public environments [Maurel et al., 2012].

The main function of the device that should be integrated in TactiNET is controlling the amplitude and the frequency of many vibration motors. It should overcome the majority of previous mentioned drawbacks, and should have many properties and features in order to distinguish TactiNET framework from other frameworks. The most important features to be in the desired device are:

- portability: the device should be portable in order to be integrated easily with mobile devices;
- low cost;
- usability: easy to be used by the experimenter and the target users (visually impaired persons);
- lightness: the device should be light to be moved easily and to be integrated easily with mobile devices;
- noiseless: can be used in public environments;
- supports a wireless connection with touch screen mobile devices, to be moved and integrated easily with mobile devices;
- does not depend on Braille coding; and
- running in real-time.

3.3 First prototype electronic circuit

To achieve the desired objectives of TactiNET, a first prototype electronic circuit has been designed. This circuit is a wireless interface connected with two actuators. The circuit controls the vibration intensity (a range of amplitude from 0 to 255) of the two actuators with a range of frequencies goes from 0Hz to 250Hz [Rabeb et al., 2012]. the actuators do not allow to control independently the amplitude and the frequency of the vibration.

During the experiment executed with sighted and blind persons using this circuit, only one actuator has been used. This option has been chosen in order to avoid any confusion may be happened to the person that tests the device from using more than one actuator. In addition to these reasons, a study performed in 2011 to analyze the parallel processing of coarse haptic information on 2-D haptic display, found that multiple contacts do not improve performance compared to a single contact in terms of both time and accuracy [Burch et al., 2011]. So the main focus during running the experiments was to study first the effect of one actuator on perceiving geometrical shapes, then in next phases, it could be possible and interesting to make the same experiments using more than one actuator and comparing the results.

Figure 3.3 presents the used actuator [Precisionmicrodrives-vibro-motor, 2016]. This actuator of type ERM (Eccentric Rotary Mass) is produced by Precision Microdrives company [Precisionmicrodrives, 2016]. Its body diameter is 10mm, and its weight is 1g.

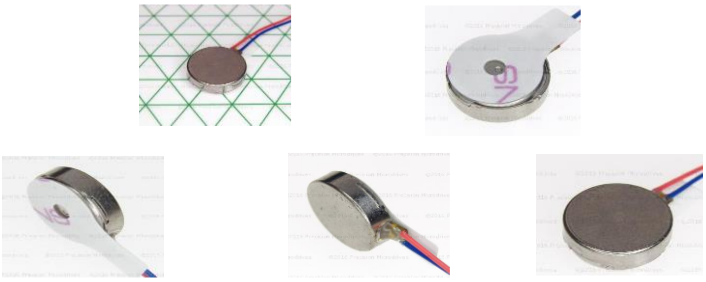


Figure 3.3 the used actuator [Precisionmicrodrives-vibro-motor, 2016].

The designed electronic circuit is presented in figure 3.4. This circuit provides a bluetooth connection with other devices support bluetooth connection.

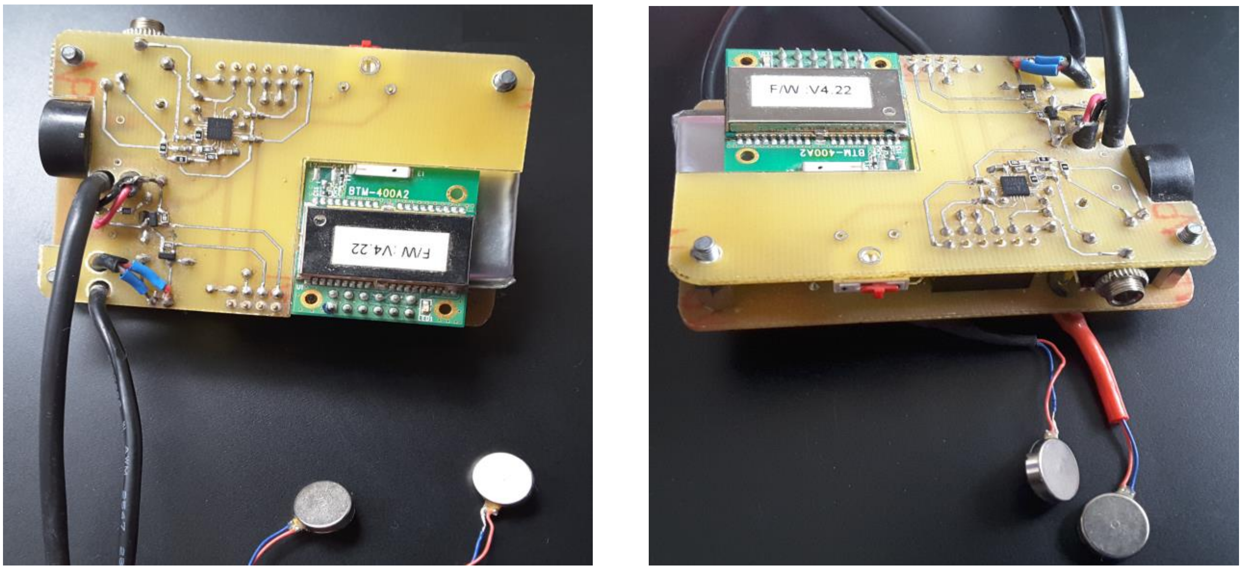


Figure 3.4 The designed electronic circuit.

The actuator could be placed on any part on the body. During the experiment, it has been placed on the wrist (either on the left or right hand, depending on the user preference). This option has been chosen depending on a study performed in 2009 that proposes a tactile feedback for text entry on tabletop computers [McAdam et al., 2009]. The authors used a actuator similar to the one described in this section to support a tactile feedback while the user enters a text on tabletop computers. The authors evaluated putting the vibrator on many locations of the body (wrist, upper arm, chest, belt, trouser pocket). The performed work concluded that placing the actuator on the upper arm or on the wrist gives the best results in term of text entry rate [McAdam et al., 2009].

To control the vibration intensity of the used actuator, an Android program dedicated on a tablet has been implemented. The used tablet is Samsung GALAXY Tab 2, 10.1inch, and its dimensions' height, width, and depth are respectively 175.3 mm, 256.7 mm, and 9.7 mm [Samsung_galaxy_tab_2, 2016]. Its Android operating system version is 4.1.2. The tablet and the circuit are connected via a bluetooth connection. The designed Android program displays an image on the screen and detects where the user touches the tablet screen. Then, the gray level of touched pixels is transmitted as amplitude values to the embedded device. Details of the designed Android program, the properties of displayed images, and the results of the achieved experiment are presented in chapter 4.

Despite that the first designed prototype has many properties and features common with the optimal properties for the desired device. But, there are also some drawbacks. **The main drawback** is its inability to control independently the frequency and the amplitude of the designed actuator during running the experiments. Controlling the frequency and the amplitude is necessary in designing the resulted vibrating pages.

To overcome this drawback, a second version has been developed when the ANR project ART-ADN started. It was designed and built by a research engineer financed by ART-ADN project [Radu, 2015]. The new version is more adapted to the desired requirements, and it was used essentially in three of the realized experiments. Its properties, components, and features are discussed in next section.

3.4 Second prototype electronic circuit

3.4.1 Introduction to current TactiNET hardware prototype

TactiNET hardware device is a fully functional wireless interface that provides communication between an electronic device (base device) and an array of 8 satellites that control 8 different actuators [Radu, 2015]. Each satellite is connected to the main device via a cable that provides both power and communication. Figure 3.5 presents the main schema of TactiNET hardware components [Radu, 2015], and figure 3.6 presents an example of using TactiNET (with 2 vibrators) with a tablet device.

In order to add more feedback to the system, a thermal Peltier satellite has been added to the system design. The thermal Peltier satellite provides a temperature feedback, either hot or cold. The idea was using this electronic element to support more semantic feedback about the navigated part on the touched-screen. For example, if the color of the navigated part is hot (such as red), the thermal Peltier satellite provides a hot temperature feedback; if the color of the navigated part is cool (such as blue), the thermal Peltier satellite provides a cold temperature feedback. This thermal Peltier satellite has not been used during the experiments due to time-constraints.

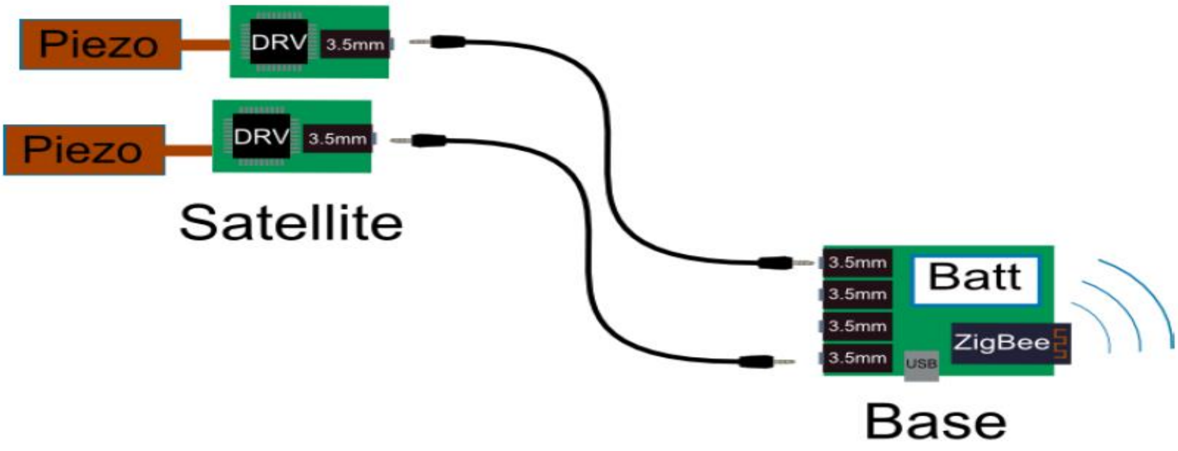


Figure 3.5 TactiNET schema [Radu, 2015].

The base electronic device connects the USB (Universal Serial Bus) stick via a bluetooth connection. The USB stick should be connected to a mobile device or a personal computer in order to control the parameters of actuators. The data packet that contains controlling information is transmitted from a tablet device or personal computer to the USB stick that transforms it via Bluetooth connection to the base device. Then the base device transforms this data packet to the target vibrators.

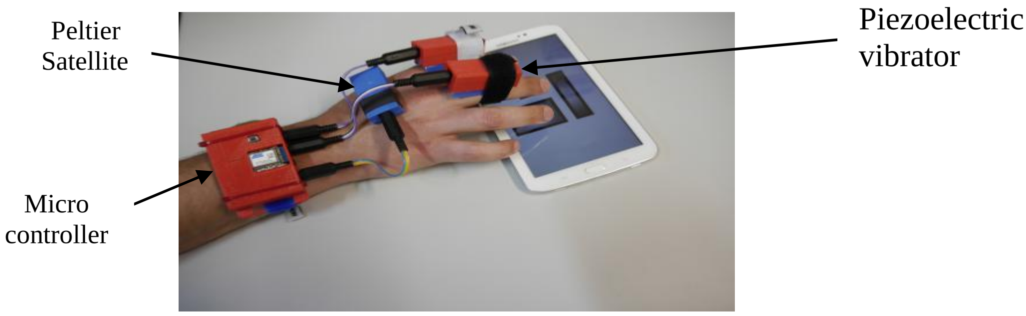


Figure 3.6 An example of using TactiNET.

Figure 3.7 presents a prototype of used actuators (Piezoelectric vibrators). Figure 3.8 presents prototypes of actuators connected with the base device by a cable.

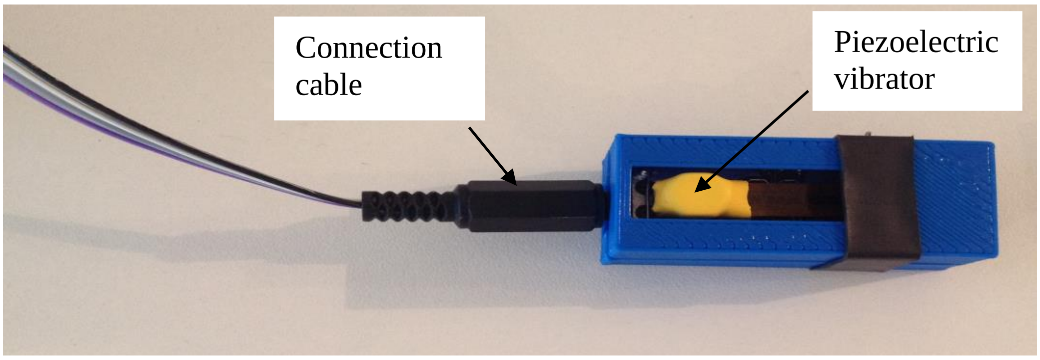
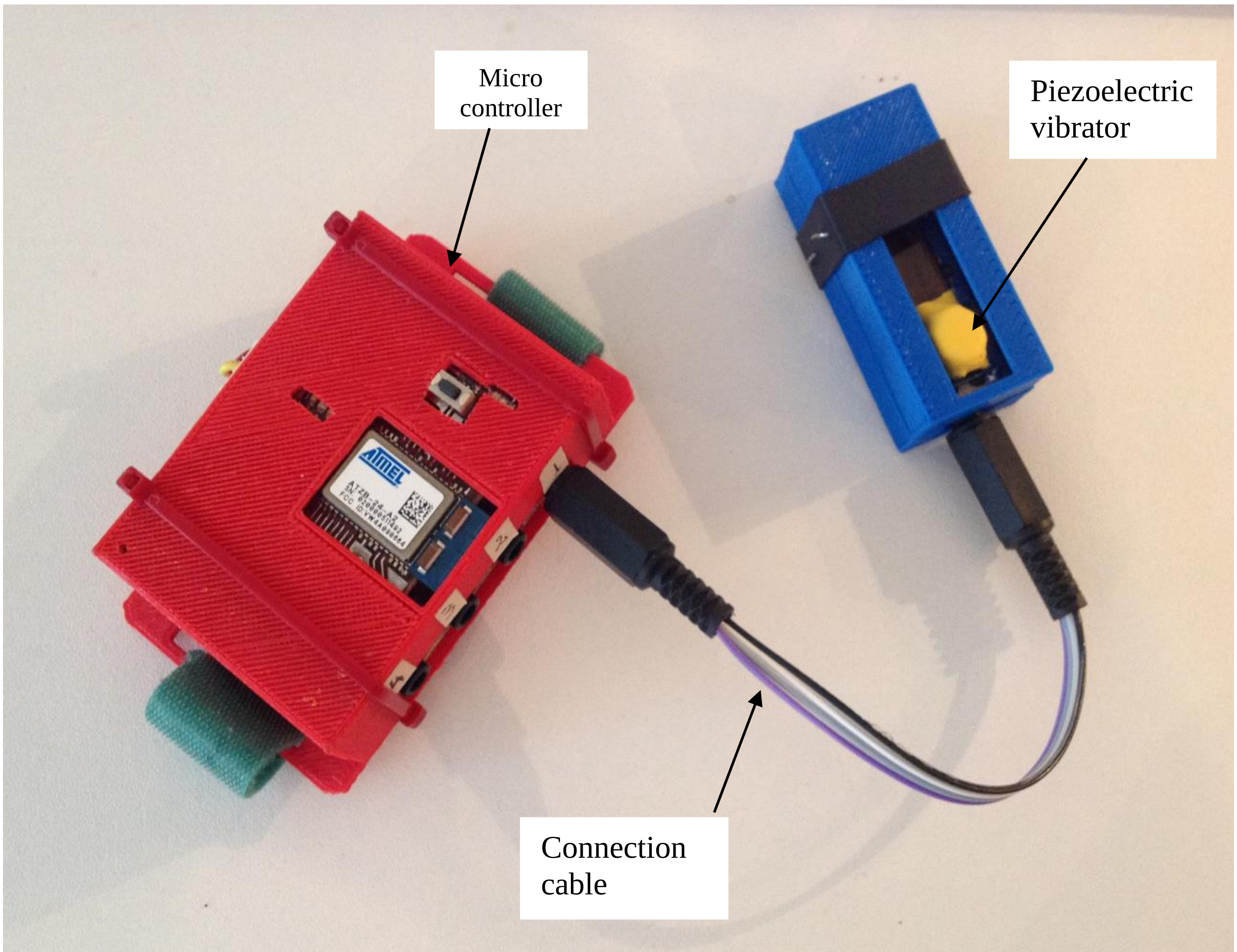


Figure 3.7 A prototype of used actuators.



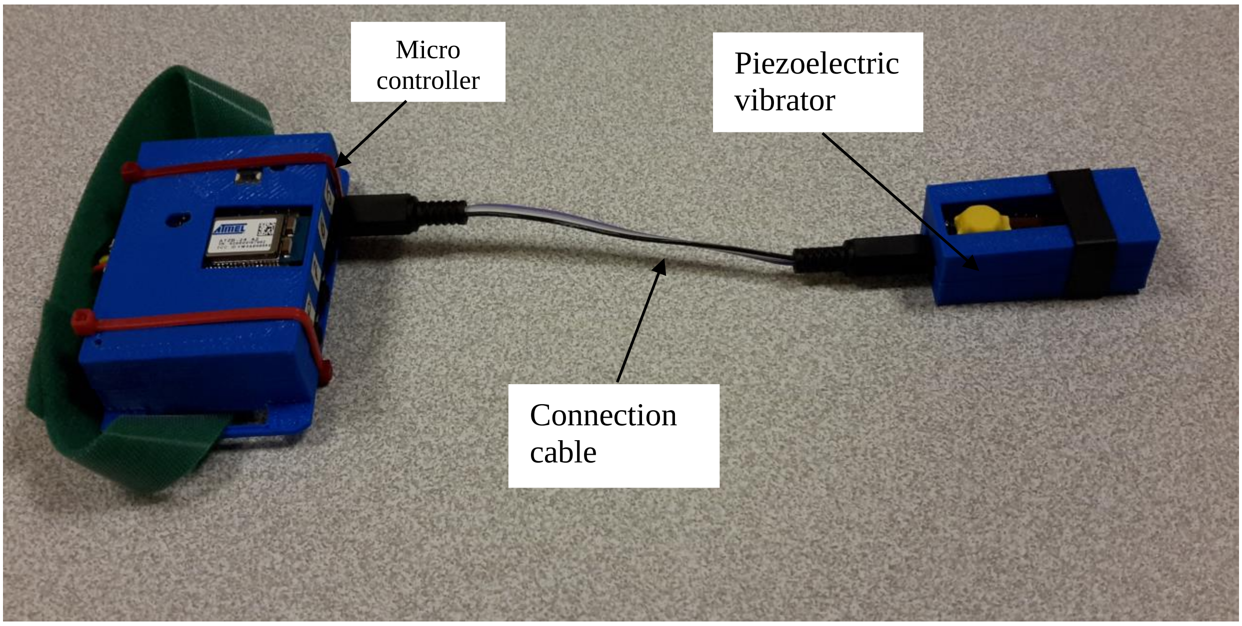


Figure 3.8 Examples of actuators connected with the base device.

Figure 3.9 presents the main components of TactiNET:
1) a tablet for controlling the parameters of actuators (frequency and amplitude);
2) a USB stick connects the base device via a bluetooth connection;
3) the base device;

4) an actuator connected with the base device by a cable; and
5) a tablet for navigating the presented shapes.

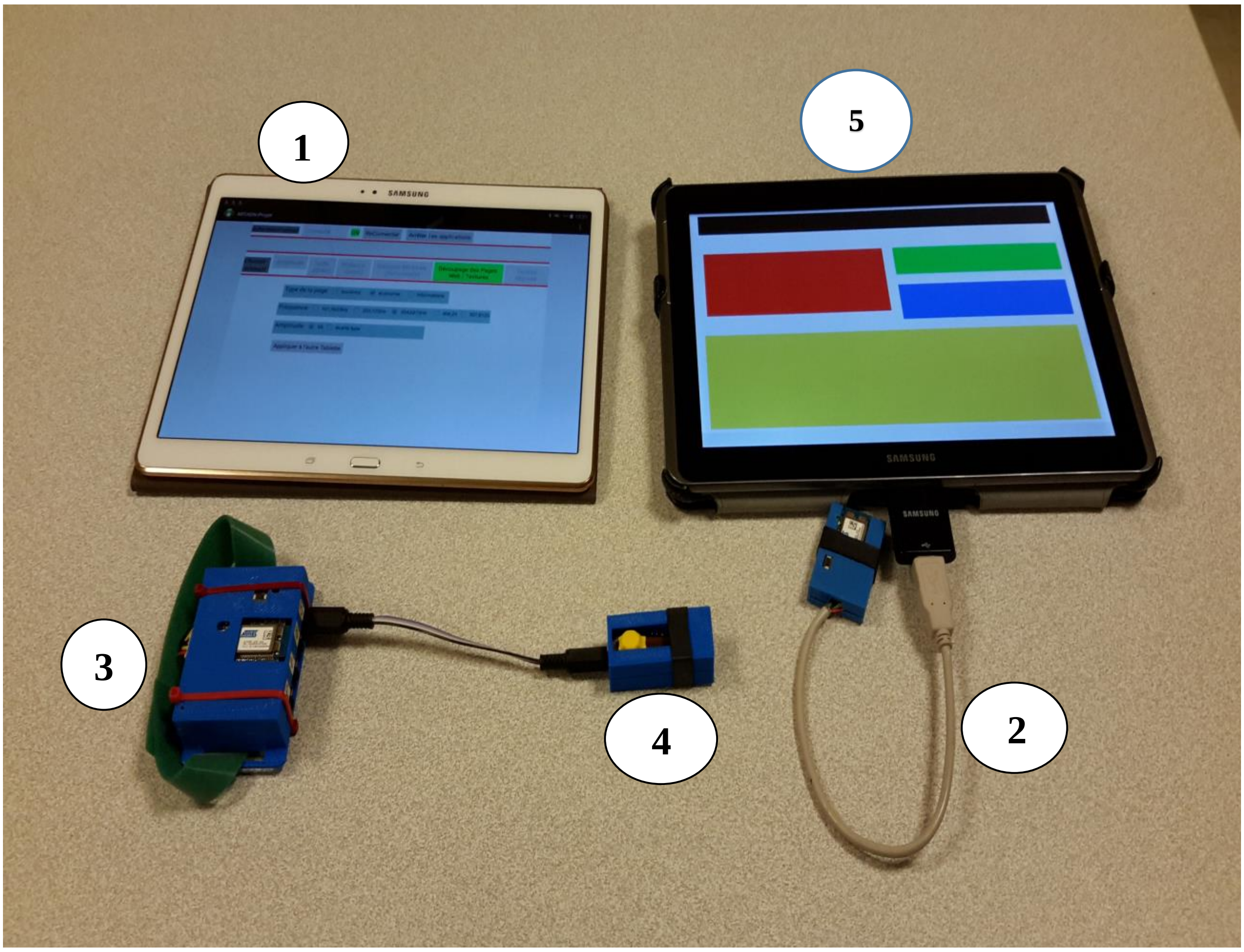


Figure 3.9 Components of TactiNET.

A packet-based communication protocol has been proposed for the connection between the base device and the tablet. The packet length was fixed to 9 byte characters. Each character is represented via a standard ASCII coding (American Standard Code for Information Interchange). In case the packet does not have the required format, it will be ignored by the device without any notification. The structure of the packet is presented in table 3.1.

Table 3.1 Structure of TactiNET communication packet between the base device and the tablet.

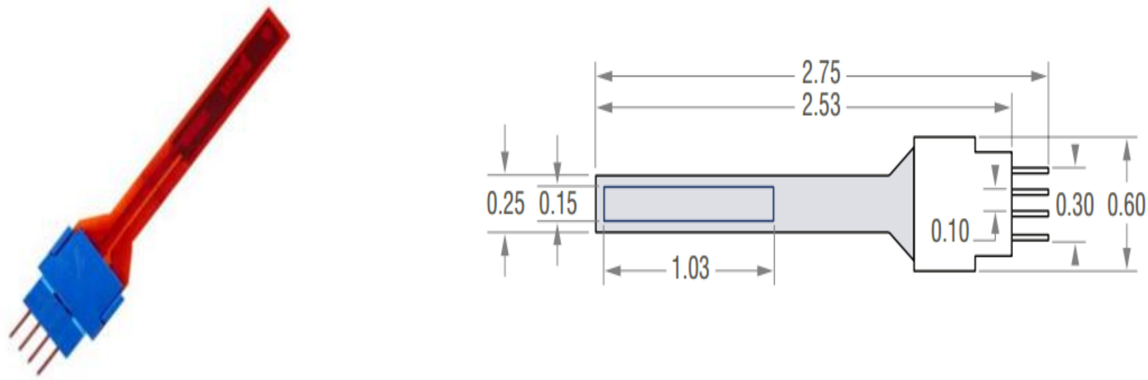
Character Number	Meaning
1	The first character represents the **beginning** of the packet. This character must be represented by a star symbol (*) or the hexadecimal equivalent value of a star symbol (0x2A).
2	The second character represents the **address** of the target satellite. The target satellite controls an actuator for which the message is destined. This character can represent values from 1 to 8 in ASCII coding or 0x31 to 0x38 in hexadecimal format.
3-4-5	These three characters represent a **virtual** value of vibration **frequency** for the actuator controlled by the target satellite. Each character can represent values from 0 to 9 in ASCII coding, or from 0x30 to 0x39 in hexadecimal format. These three characters produce a value that does not represent the real frequency value,

	but it represents a virtual one. To obtain the real frequency, this virtual value must be multiplied by a constant value equals 7.8125. For example, if the virtual value equals "064", so the real frequency is 500Hz (64x7.8125). These three characters can represent together values from 0 to 999. But the maximum value for virtual frequency is 255 that equals a real value 1992.1875Hz (255x7.8125). So during running the experiments, any virtual value greater than 255 will be truncated to 255.
6-7-8	These three characters represent the vibration **amplitude** value of the actuator controlled by the target satellite. Each character can represent values from 0 to 9 in ASCII coding, or from 0x30 to 0x39 in hexadecimal format. These three characters can represent together values from 0 to 999. But the maximum value for amplitude is 255. So during running the experiments, any value greater than 255 will be truncated to 255. The real voltage value of the amplitude depends mainly on the mechanical resistance of the skin for each participant. Considering that the mechanical resistances of skin for the participants are unknown, the amplitude values were described as natural numbers in the range 0 and 255. 0 mean vibration. 255 means the maximum value of the amplitude.
9	The last character represents the **end** of the packet. It must be an exclamation mark (!) in ASCII coding or 0x21 in hexadecimal format.

Another command has been implemented in order to be used for getting more information about the running state of the actuators. A packet of the form "***A**GO0000!" (called the state packet) is used to check if the addressed actuator is still vibrating or not. In this packet the address is selected by replacing the character "A" by the desired address. In this case, the character "A" can be represented by values from 1 to 8. When sending this packet information to the base device. The base device will reply with a hexadecimal value. This value is "0x00" if the target actuator is not vibrating, or "0x01" if it is vibrating.

3.4.2 Technical details of current TactiNET hardware prototype

The used vibrators in TactiNET are piezoelectric actuator of type QuickPac (QP22B) [QP22B, 2016]. Figure 3.10(a) presents an example of this type of actuators, and figure 3.10(b) presents its dimensions (all dimensions are in inch unit) [QP22B, 2016].



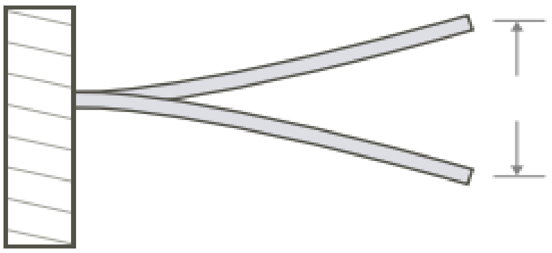
(a) The actuator QuickPac (QP22B) (b) Dimensions of actuator QuickPac (QP22B)

Figure 3.10 An example of the used piezoelectric actuator QuickPac (QP22B) [QP22B, 2016].

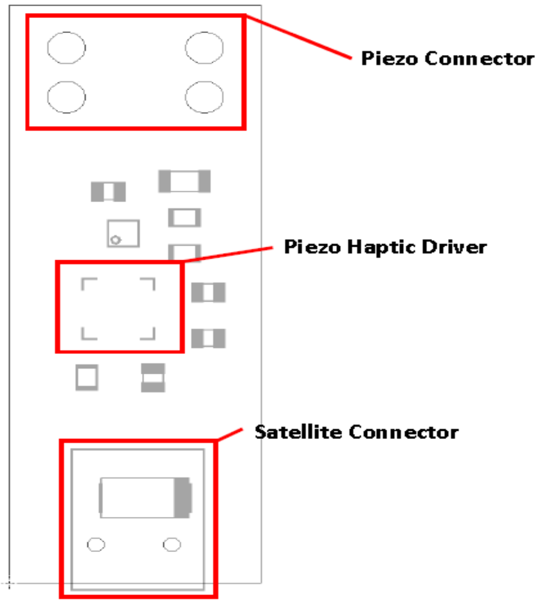
The total length of QuickPac QP22B actuator is 2.75 inch (69.85 mm), its width is 0.6 inch (15.24 mm), and its height is 0.03 inch (0.762 mm). The shape of this actuator is rectangular supported from one side of its terminations by four connector pins.

The main concept of piezoelectric materials is that when applying a mechanical stress on piezoelectric materials, a voltage will be generated. Conversely, an applied voltage will deformate the material. If a varying voltage is applied, the material will vibrate [QuickPack-actuator, 2016].

Only one part of the actuator is situated on a satellite, and some part of the piezoelectric element can be still unfixed. When a varying voltage is applied the unfixed part of the piezoelectric element will be moved generating the vibration sense. This type of configuration is called cantilever configuration. Figure 3.11(a) presents how the actuator can be moved vertically [QuickPack-actuator, 2016] (cantilever configuration), and figure 3.11(b) presents a diagram of the top layer of the piezoelectric satellite that connects a piezoelectric actuator [Radu, 2015].



(a) Cantilever configuration



(b) Top layer of the piezoelectric satellite

Figure 3.11 Cantilever configuration and the top layer diagram of the used piezoelectric satellite.

The base device features an Atmel ATZB-24-A2R ZigBit module [ATMEL_MOD_ZIGBIT, 2016]. It is responsible of communicating with the USB stick, and controlling the actuators. It was designed to be used as easily and friendly as possible. A reset button reinitiates the device if there is any technical problem during running the experiments. There are three LEDs (Light-Emitting Diode) that identify the state of the battery (battery connected, battery charging, and battery pre-charge procedure/battery fault).

3.5 Conclusion of Chapter 3

Designing a portable, usable, noiseless, real-time running, and friendly-using framework is essential to guarantee optimal technical and cognitive conditions during running experiments with target users. The first version of TactiNET has a main drawback, which is its inability to control frequencies of used actuators. Current version of TactiNET supports controlling the frequency and the amplitude of many actuators. These frequencies and amplitudes represent semantic meanings of web pages segments. Extracting these semantic meanings require designing software components and constructing many resources. Integrating these software components with the hardware parts helps designing a compatible tactile vision sensory substitution system aims to improve the navigation for blind people to web pages displayed on digital tablets. This chapter discussed the technical hardware properties and the features of designed versions of TactiNET. Next chapter will discuss details of the software components and used resources.

Chapter 4:
Software Implementation

Résumé : De nos jours, les appareils portatifs sont de plus en plus utilisés, en particulier pour la navigation sur le web. Mais la petite taille des écrans de ces dispositifs nécessite d'adapter le contenu de la page Web pour être présentée plus facilement, car la majorité des pages Web sont conçues pour être présentées sur des ordinateurs personnels [Hattori et al., 2007]. Une étape fondamentale dans le processus de l'adaptation automatique d'une page Web est de percevoir sa disposition visuelle et d'extraire sa structure de modèle des objets du document (DOM). Dans ce chapitre, nous présentons les principaux composants et ressources logiciels utilisés pour construire le système de substitution sensorielle visuo-tactile TactiNET. Un regroupement agglomératif des segments visuels et textuels d'une page Web est présenté. Cet algorithme de segmentation adapté au Web est dédié à l'accès vibro-tactile sur les dispositifs avec un écran tactile et il est fondamental dans TactiNET. L'algorithme suggéré dépend principalement de quelques notions de base de la théorie de la Gestalt qui étudie comment les personnes voyantes perçoivent les formes géométriques [Ellis, 1938] [Sternberg et al., 2012] [Soegaard, 2002]. Une comparaison entre la segmentation automatique et la segmentation manuelle des pages Web est également présentée dans ce chapitre. Les objectifs de cette comparaison sont, d'une part, de savoir comment les utilisateurs voyants comprennent la structure de la page Web en fonction de leur perception visuelle ; et d'autre part d'explorer les principales différences entre la segmentation automatique et la segmentation manuelle.

Effectuer de nombreuses expériences avec des personnes voyantes et aveugles en utilisant TactiNET est limité dans le temps. Donc, construire un corpus basé sur le Web qui contient de nombreuses catégories de pages Web (touristique, e-commerce et informations) et l'extraction d'un représentant de page Web pour chaque catégorie est fondamentale. Dans ce chapitre, nous présentons la méthodologie de construction du corpus Web ART-ADN, ses propriétés d'accessibilité et ses propriétés technologiques. En plus de la méthodologie d'extraction des représentatives des pages web.

4.1 Introduction of Chapter 4

Nowadays, hand-held devices are being used more and more, especially for web navigation. But the small screen size of these devices requires adapting the web page contents to be browsed more conveniently, because the majority of web pages are designed to be presented on personal computers [Hattori et al., 2007]. A fundamental step in a successful automatic adaptation process of a web page is perceiving its visual layout and mining its document object model (DOM) structure. In this chapter, the main software components and resources used to construct TactiNET software are described. An agglomerative graph-based clustering of visual and textual web page segments is presented. This web-adapted segmentation algorithm is dedicated to vibro-tactile access on touch-screen devices, and it is fundamental in TactiNET framework that aims to enhance the ability of visually impaired persons to understand the 2-dimensional web page layout by converting web pages into vibrating pages using a graphical vibro-tactile language. The suggested algorithm depends mainly on some grouping basics of Gestalt theory that studies how sighted persons perceive the geometric forms, and it explains why some objects are perceived as in groups [Ellis, 1938] [Guillaume, 1979] [Sternberg et al., 2012] [Soegaard, 2002]. A comparison between automatic and manual segmentation of web pages is also presented in this chapter. The objectives of this comparison are, on the one hand, to know how sighted users understand web page layout structure based on their visual perception, and on the other hand, to explore the main differences between automatic and manual segmentation.

Performing many experiments with sighted and blind persons using TactiNET is time-constrained; so constructing a web-based corpus that contains many web pages categories (touristic, e-commerce, and news) and extracting a web page representative for each category is fundamental. In this chapter, the methodology for constructing the ART-ADN web-based corpus and its accessibility and technological properties are presented; in addition to the methodology of extracting the web pages representatives.

4.2 Gestalt Theory

Gestalt theory or Gestalt psychology is a set of laws and basics that describe how sighted people perceive the geometric forms. Gestalt is a German word refers to the "form" or "shape". The main concepts of Gestalt theory were first introduced in psychology and philosophy domains in 1890 by Christian von Ehrenfels to explain observations of wholeness in perception the forms [Ellis, 1938] [Guillaume, 1979] [Sternberg et al., 2012]. This theory was developed mainly between 1930 and 1940 [Guillaume, 1979]. The main idea of Gestalt psychology is that the mind tends to form a global whole from many sub-forms. Gestalt theory explains why some objects are perceived as in groups but other objects not [Sternberg et al., 2012], and it describes how the sighted persons perceive the whole structure using laws of grouping (or what is called "the perception of groups") [Sternberg et al., 2012], which are:

4.2.1) law of proximity: a sighted person perceives a set of objects that are close to each other as a group (cf. figure 4.1);

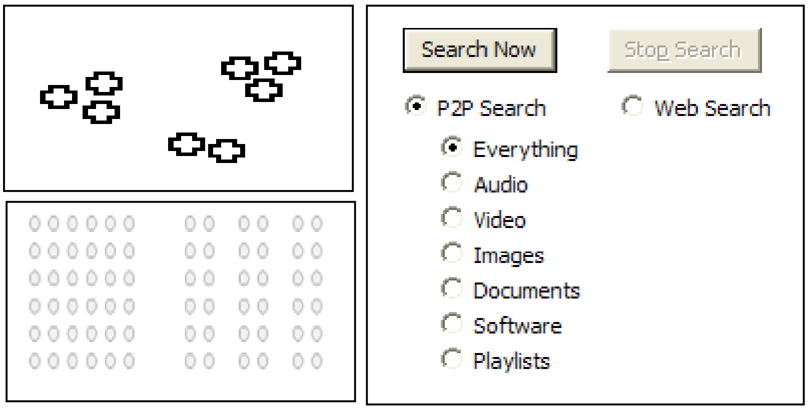


Figure 4.1 Examples of law of proximity [Ellis, 1938] [Sternberg et al., 2012] [Soegaard, 2002].

4.2.2) law of similarity: in set of objects, objects which are similar to each other are perceptually grouped together (cf. figure 4.2);

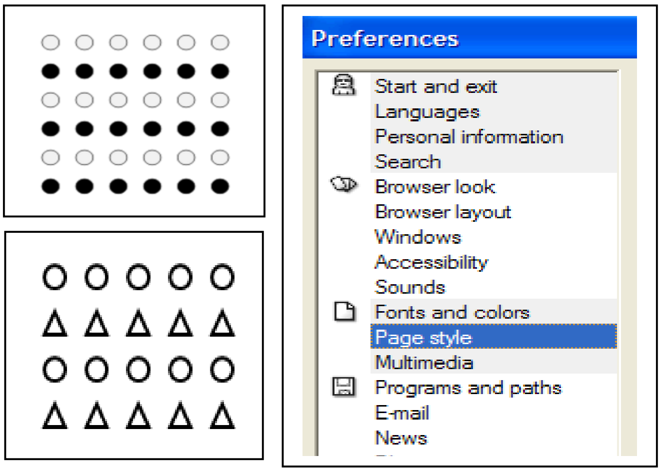


Figure 4.2 Examples of law of similarity (Gestalt theory) [Ellis, 1938] [Sternberg et al., 2012] [Soegaard, 2002].

4.2.3) law of closure: sighted persons perceive objects such as letters, shapes, pictures, etc., as being whole even when they are not complete (cf. figure 4.3);

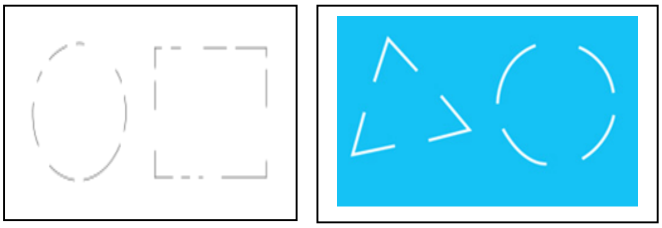


Figure 4.3 Examples of law of closure (Gestalt theory) [Ellis, 1938] [Guillaume, 1979].

4.2.4) law of symmetry: in a set of objects that contains some symmetrical objects, the mind divides the objects into symmetrical parts. Therefore, even if two symmetrical elements are not connected together the mind perceptually connects them to form a group (cf. figure 4.4);

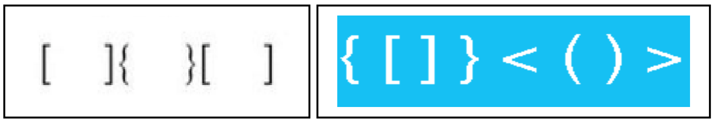


Figure 4.4 Examples of law of symmetry (Gestalt theory) [Ellis, 1938] [Guillaume, 1979].

4.2.5) law of continuity: elements of objects tend to be grouped together, and therefore integrated into perceptual wholes if these elements are aligned (arranged) within an object (cf. figure 4.5)**;**

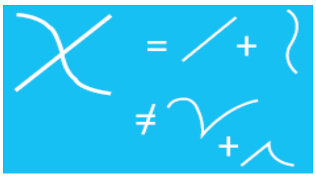


Figure 4.5 An example of law of continuity (Gestalt theory) [Guillaume, 1979].

4.2.6) law of good Gestalt (law of Prägnanz) (figure-ground principle): elements of objects tend to be perceptually grouped together if they form a pattern that is regular, simple, and orderly. In figure 4.6(a) a logo for "Gnome Desktop Environment", can be viewed as both a "G" letter and a footprint [Soegaard, 2002]. In figure 4.6(b) the Macintosh logo can be viewed as a regular happy face, and a happy face in profile (looking at a computer screen) [Soegaard, 2002].

a) Gnome Desktop Environment logo b) Macintosh logo

Figure 4.6 Examples of law of good Gestalt (Gestalt theory) [Guillaume, 1979].

4.2.7) law of past experience: sighted persons, under some circumstances and depending on some contexts, perceive and categorize visual stimuli according to their past experience and knowledge (cf. figure 4.7).

Context helps us to be able to recognize letters in many different styles.

Context helps us to be able to recognize letters in many different styles.

Figure 4.7 Examples of law of past experience (Gestalt theory) [Guillaume, 1979].

The previous Gestalt theory laws are essential in any segmentation and grouping process of web page elements. Next section discusses in details the suggested algorithm for segmenting and clustering the HTML elements of web pages.

4.3 Segmentation and Clustering the HTML Elements of Web Pages

Segmenting a web page is a fundamental phase for understanding its global structure. Extracting the global structure of web pages is useful in many domains such as information retrieval, data extraction, and similarity of web pages. Conveying additional spatial information and perception of page layout enhances the exploration process and navigation strategies for visually impaired persons [Murphy et al., 2008]. Extracting semantic information and reformatting pages can promote levels of accessibility [Murphy et al., 2008].

In image processing, segmentation refers to the process of partitioning a digital image into multiple segments [Singh et al., 2013]. Web page segmentation is separating web page contents into structural and semantic cohesive blocks [Alcic et al., 2011]. Clustering is the process of organizing objects into groups whose members are similar in some way [Alcic et al., 2011]. Web page contents clustering and segmentation could be useful in many applications, such web content search, web page categorization, web page adaptation for mobile devices, and web image indexing [Alcic et al., 2011]. A cluster is a set of objects that are similar between them and are dissimilar to the objects belonging to other clusters [Alcic et al., 2011]. In web pages, a segment is a visual region that a sighted user can identify as distinct from other parts of the page [Pnueli et al., 2009].

The process of segmenting and clustering web page contents is known in the web mining literature by many expressions such as: web page layout modification, web page restructuring, and web page zooming [Hattori et al., 2007]. This section describes the contribution to construct and evaluate a web-based segmentation algorithm. The contribution is threefold:

- designing an algorithm for segmenting a web page into blocks and grouping its components into zones in order to enhance the ability of visually impaired people to perceive the web page layout;
- conducting an experiment for exploring how users understand web page layout structures based on their visual perception; and

- evaluating the results obtained from the suggested algorithm in order to compare the differences between the automatic and manual web page segmentation.

4.3.1 State of the art of web pages segmentation and choosing an appropriate approach

Many approaches have been proposed for segmenting web pages, such as:

- **DOM-based segmentation approach**: this approach depends on parsing and analyzing the web page DOM tree, and extracting the main segments of web page DOM tree tags by applying a series of filters, rules, and heuristics [Sanoja et al., 2013] [Gupta et al., 2003] [Bar-Yossef et al., 2002] [Yi et al., 2003];
- **Vision-based segmentation approach:** this approach divides the web page depending on the visual view of web page contents after rendering it on a web browser [Deng et al., 2003] [Song et al., 2004] [Lei et al., 2009] [Burget et al., 2009] [Cormier et al., 2016];
- **Image processing based segmentation approach**: this approach captures an image for the visual view of a web page, and then it depends on image processing techniques to divide the captured image into sub-blocks [Cai et al., 2004] [Cao et al., 2010];
- **Text-based segmentation approach:** this approach focuses on extracting only textual information in a web page. The approach divides the textual web page contents into blocks depending on many lexical and semantic similarity relations [Foucault et al., 2013] [Ruijie et al., 2010];
- **Fixed-length segmentation approach**: this approach divides a web page into fixed length blocks (paragraphs), after removing all HTML tags, where each paragraph contains a fixed number of words [Callan, 1994];
- **Densitometric analysis based segmentation approach**: this approach depends on methods applied in quantitative linguistics, where text-density refers to a measure for identifying important textual segments in a web page [Kohlschütter et al., 2008]; and
- **Graph-based segmentation approach**: this approach depends on transforming the visual segments of a web page into graph nodes, then applying many common graph methods on these nodes for combining them into blocks, and clustering these nodes in many clusters [Chakrabarti et al., 2008] [Liu et al., 2011].

While choosing the segmentation algorithm dedicated for TactiNET, there were two possibilities, either choosing one of existed approaches and integrating it directly in TactiNET framework, or designing a new algorithm more optimized for the framework requirements. The majority of previous indicated approaches are interesting; but considering that the main idea of TactiNET is more oriented to convert the visual web page layout into a vibrating page, a specific attention has been drawn to approaches that deal with the visual contents (such vision-based segmentation approach, image processing based segmentation approach, and graph-based segmentation approach) more than those approaches that deal only with textual contents (such as text-based segmentation approach, fixed-length segmentation approach, and densitometric analysis based segmentation approach). Some available visual oriented approaches have been tested and evaluated such as VIPS (Vision-based Page Segmentation Algorithm) [Deng et al., 2003] and PageLyzer [Sanoja et al., 2013], and the following results have been found:

- the majority of the proposed approaches are targeted to personal computers with big screen sizes, and not for mobile devices with small screen sizes;
- the proposed approaches do not support an option (parameter) to choose the desired number of clusters (blocks or zones of segmented HTML elements), which is very critical argument in TactiNET.

For these reasons, the option of designing a new algorithm more adaptable with the framework requirements has been chosen.

To design a new segmentation approach dedicated to TactiNET; first, more attention has been given to image processing techniques and especially for the techniques of mathematical morphology [Serra, 1983]. Mathematical morphology is a theory most commonly applied to digital images. This theory is used for analyzing and processing of geometrical structures in the image based on a set of geometrical and topological functions [Serra, 1983]. There are two types of mathematical morphology operations [Serra, 1983]:

- simple operations such erosion and dilation (cf. figure A.1 in appendix A);
- advanced operations such opening, closing, skeletonization, filling holes, and edge detection (cf. figure A.2 in appendix A);

After applying many basic simple and advanced mathematical morphology operations, and combining many of the advanced operations (more examples in appendix A), the following result has been found: applying mathematical morphology operations to segment web pages is not the most efficient way, due to:

- the confusion between the boundings of HTML elements in a web page and the boundings of objects in an image in the web page. This confusion produces many errors in next steps when clustering the objects of a web page;
- in addition to the complexity of relating the extracted objects in a web page image with their HTML tags in HTML source.

For these reasons, the option of developing a segmentation algorithm of web pages depending on image processing techniques had been canceled, and more attention has been drawn to develop a new algorithm with following requirements:

- easy to be integrated with TactiNET framework;
- can extract the visual layout of a web page;
- do not depend on web page meta data to extract the visual layout. This algorithm will be discussed in details in next section.

4.3.2 Suggested agglomerative graph-based clustering algorithm

Most of segmentation algorithms render first the web page using a web browser, and then segments the HTML elements into many blocks depending on their visual layout. The suggested algorithm consists of three basic phases:

- extracting the visual parameters of HTML elements (vision-based phase),
- filtering and reorganizing HTML elements (DOM-based phase), and
- clustering the extracted segments (an agglomerative graph-based phase).

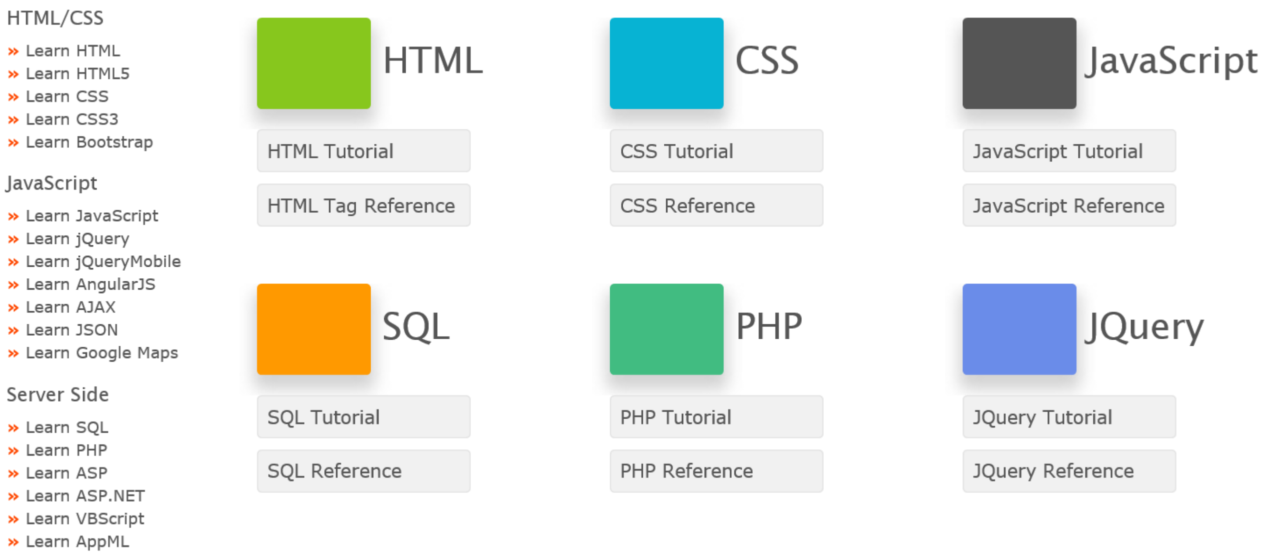
These three phases have been suggested after analyzing the contents of about 154 web pages collected manually from many newspapers sites, web developer information sites, and e-commerce sites (www.leparisien.fr, www.lefigaro.fr, www.liberation.fr, www.amazon.fr, www.materiel.net, wwww.photobox.fr, www.w3schools.com).

4.3.2.1 Vision-based phase

In this phase, a web page is rendered using Selenium Web Driver [Seleniumhq, 2016] and PhantomJS [Phantomjs, 2016] web browser to get its visual structure by injecting Java-script code inside the HTML source code of the rendered web page. The obtained visual structure indicates the global hierarchy of the rendered web page. This phase assigns additional information for each DOM HTML element such:

- DOM Xpath (an expression that presents the element path in the DOM tree);
- the element bounding box (location [X0, Y0], and size [height and width]); and
- CSS (Cascading Style Sheets) information.

Figure 4.8 views a representation of the main bounding boxes in a part of the home page of site www.w3schools.com. Rectangles in figure 4.8(b) represent the bounding boxes of HTML elements in figures 4.8(a).



(a) A part of the main page of site www.w3schools.com

(b) bounding boxes of HTML elements in image (a)

Figure 4.8 A representation of bounding boxes in the home web page of www.w3schools.com.

The input of this phase is a web page HTML source code, and its output is an augmented HTML web page with injected information about bounding boxes, CSS information, and DOM XPath for each HTML element. In next sections, it is referred to bounding boxes by blocks (i.e. each bounding box represents an HTML element, and may contain other sub bounding boxes). Figure 4.9 represents an example of inserted information in an HTML source code.

This phase has been implemented in collaboration with SemioTime company [SemioTime, 2016] by designing a dedicated web service for the project ART-ADN. The input of this web service is a list of web pages URLs. For each input web page URL, the web service returns the following items:

- an image file represents the visual rendering of the web page;
- an HTML file contains the HTML source code of the web page;
- an enriched (augmented) HTML file contains the HTML source code of the web page with the enriched information for each HTML element (XPath, CSS information, and bounding

boxing information); and

- a SVG (Scalable Vector Graphics) file contains two-dimensional representation of the bounding boxing information of the input web page HTML elements. Figure 4.10(a) represents a part of a web page (www.leparisien.fr), and figure 4.10(b) views its SVG bounding boxing representation.

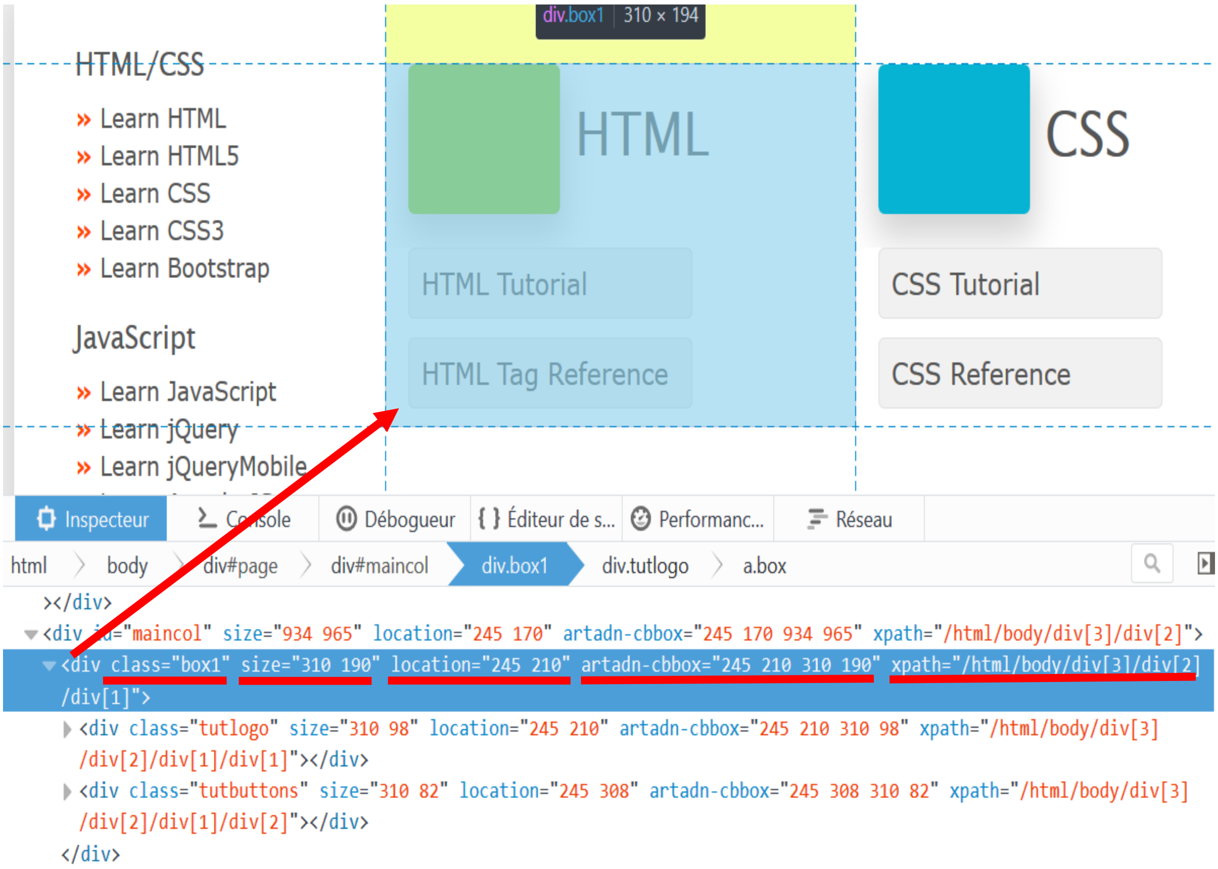


Figure 4.9 An example of inserted information in HTML source code.

(a) A part of a web page (www.leparisien.fr) (b) SVG bounding boxing representation of image (a)

Figure 4.10 A part of a web page (www.leparisien.fr) and its vision-based segmentation.

The designed web service supports the previous indicated outputs by executing the following steps for each web page URL [Giguet et al., 2010] [Giguet et al., 2009]:

a. running the web driver and rendering the web page using PhantomJS web browser,
b. downloading the files related to the web page (images, JavaScript files, and CSS files),
c. capturing an image for the visual rendered page, and generating the image file,
d. obtaining the DOM-tree, and generating the main HTML file,
e. for each element e in DOM-Tree elements:
  e.1. getting information about element e,
    (XPath, CSS information, and bounding boxing information),
  e.2. injecting the obtained information in the HTML source,
f. generating an enriched HTML file (DOM-Tree with injected information),
g. generating a SVG file.

4.3.2.2 DOM-based phase

After obtaining the Xpath information, CSS information, and the visual bounding boxing information of a web page, its DOM structure is analyzed and reconstructed by applying filters and textual re-organization rules. The DOM elements are divided depending on the specification of HTML5 content models [Content-models, 2016] proposed by the World Wide Web Consortium (W3C) [W3C, 2016]. This specification divides the HTML tags into 7 categories:

- **metadata content**: sets up the presentation or behavior of the rest of the content such as <link>, <meta>, <noscript>, <script>, <style>, and <title>;
- **flow content**: used in the body of the HTML document such as <a>,
, <button>, <div>, <figure>, <footer>, <form>, <h1>, <h2>, <h3>, <h4>, <h5>, <h6>, <header>, <hgroup>, <hr>, <img>, and <input>;
- **sectioning content**: defines the scope of headings and footers such as <article>, <aside>, <nav>, and <section>;
- **heading content**: defines the header of a section such as <h1>, <h2>, <h3>, <h4>, <h5>, <h6>, and <hgroup>;
- **phrasing content**: texts, as well as elements that mark up texts such as <span>, <p>, <small>, <strong>, <a>, <button>, <i>, <input>, <label>, and <select>;
- **embedded content**: that imports another resource into the document such as <audio>, <canvas>, <iframe>, <img>, <math>, <object>, <svg>, and <video>; and
- **interactive content**: content intended for user interaction such as <a>, <button>, <input>, <menu>, and <select>. These groups are illustrated in figure 4.11.

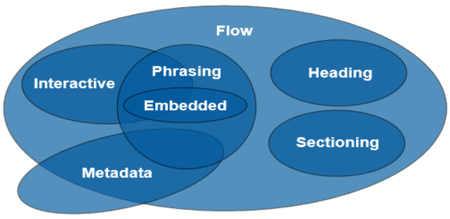


Figure 4.11 Specification of HTML5 content models proposed by the World Wide Web Consortium (W3C) [Content-models, 2016].

The first applied filter is Metadata-Content-Filter, which deletes all elements considered as metadata content elements except <title> tag. These tags are deleted because they do not contain useful visual information in next phases. The deleted tags are:

- <base>
- <command>
- <link>
- <meta>
- <noscript>
- <script>

- <style>
- <comment>
-
- <doctype>

The node <title> (the page title) is not deleted because the textual information included in this node could be useful for the user.

The second applied filter is Non-Visible-Nodes-Filter. This filter deletes all HTML nodes that do not affect on the appearance, for example nodes with height or width equals to “0px” (zero pixel); or nodes with style properties ("display:none" or "visibility:hidden" or "hidden:true"). After applying the previous filters, a textual re-organization rule is applied in order to enhance visualizing the information in next phases. The rule called Paragraph-Reorganization-Rule re-constructs all paragraph child-nodes in one node contains the extracted sub-texts. This rule has been suggested after analyzing many DOM structures, and observing that the text in some paragraph nodes is distributed between many child-nodes such following HTML tags:

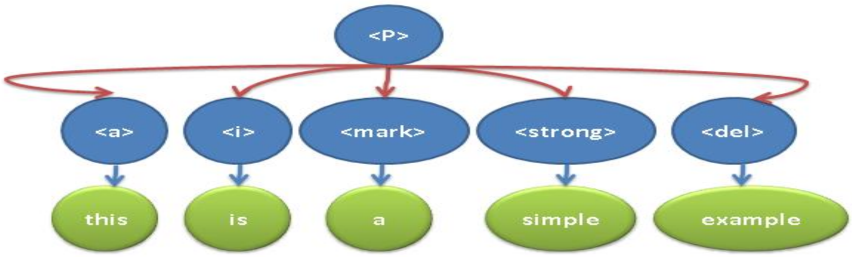
- <i> (italic text),
- <span>,
- <b> (bold text),
- <strong>,
- <em> (emphasized text),
- <small>,
- <mark> (marked text),
- <del> (deleted),
- <ins> (inserted),
- <cite> (defining a title of work),
- <u> (underline text),
- <sub> (subscript).

Extracting these sub-texts and collecting them in one text in the DOM-tree is useful and more efficient for visualizing them as one block in next phases rather than visualizing them as many separated blocks.

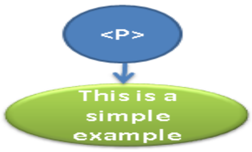
The following HTML source code is an example for illustrating the result of applying the rule:

```
<p>
    <a> this </a>
    <i> is </i>
    <mark> a </mark>
    <strong> simple </strong>
    <del> example. </del>
</p>
```

Its DOM structure is:



After applying the rule, the DOM representation is:



This rule was applied first on all tags of type <P> (paragraph), and on all tags existed in the heading content category (specification of HTML5 content models), this group contains the following nodes: h1, h2, h3, h4, h5, h6, and hgroup. Then the rule has been applied on many other HTML tags which might contain textual child-nodes such:

- <a> (hyperlink tag),
- <abbr> (abbreviation),
- <acronym> (this tag is not supported in HTML5),
- <address> (contact information for the author/owner),
- <bdi> (Bi-directional isolation),
- <button>,
- <label>,
- (list element), and
- <q> (quotation).

The tool Jsoup (Java HTML Parser) [Jsoup, 2016] has been used to access the web page DOM structure, and obtaining its HTML hierarchy. The result of this phase is a filtered DOM-tree; each of its nodes is visible and contains XPath, CSS, and bounding boxing information. The designed filters and re-organization rules have been applied on all the vision-based segmented web pages (154 pages mentioned previously). After obtaining the filtered DOM-tree, the obtained bounding boxes for each web page are represented on a tablet (the used tablet Samsung GALAXY Tab 2, 10.1inch. Its dimension's height, width, and depth are 175.3 mm, 256.7 mm, and 9.7 mm. Its Android version is 4.1.2.

After making a scaling of sizes of bounding boxes to be appropriated with the size of used tablet; scaling the sizes of obtained bounding boxes is necessary considering the difference in size between the normal web page size and the tablet screen size.

4.3.2.3 An agglomerative graph-based clustering

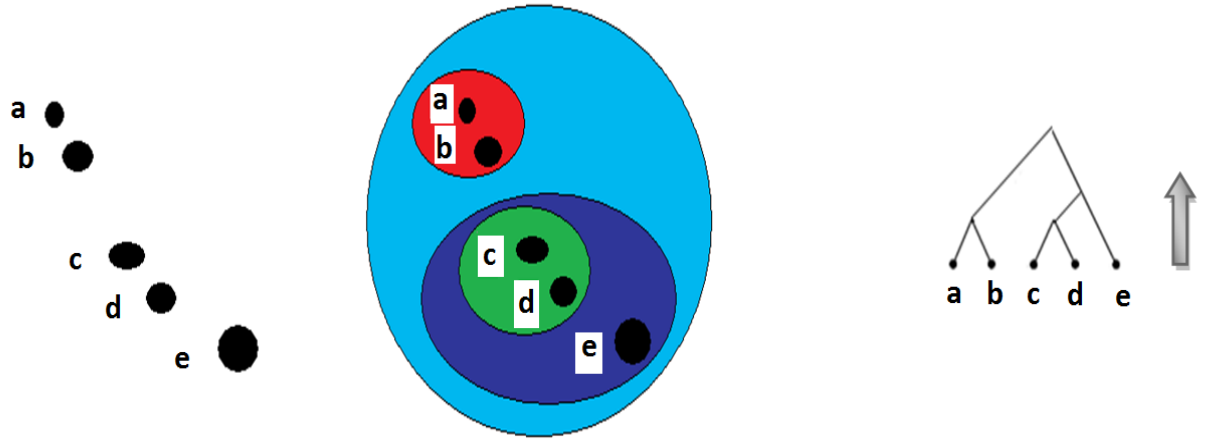
After segmenting the web page depending on its visual structures and analyzing, filtering, re-organizing its DOM-structure; a clustering method have to be applied in order to group many similar blocks together in one zone. Clustering many blocks together is necessary in order to decrease the number of presented blocks in some interfaces (instead of viewing all the blocks, one zone that represents these blocks is presented), and to group closed blocks in one zone (here, closeness depends on the distance between blocks).

To choose a clustering algorithm, the following two questions should be answered:

- what is the best representation of web page elements?
- which clustering method should be applied?

Concerning the first question, the web page has been represented as a graph, where the web page segments (blocks obtained from the first two phases vision-based phase, and DOM-based phase) represent the vertices of the graph, and the links between these segments represent the edges of the graph. In what concerns the second question, choosing a clustering method is more related to the representation method, so a graph clustering is more appropriate to be chosen. Graph clustering algorithms are divided into two major classes: divisive and agglomerative [Chen et al., 2010].

Divisive clustering is a top-down algorithm that recursively splits a graph into subgraphs. In contrast, agglomerative clustering is a bottom-up style, and iteratively merges singleton sets of vertices into subgraphs. The two types (divisive and agglomerative) are called hierarchical clustering algorithms because one cluster follows the other either by agglomerating or refining the contents [Chen et al., 2010]. The chosen clustering algorithm is the agglomerative because the nature of the proposed grouping method is a bottom up style. Figure 4.12 represents an example of an agglomerative-based clustering algorithm.



(a) Data points (b) Hierarchical clusters (c) Agglomerative clustering

Figure 4.12 An example of an agglomerative-based clustering algorithm.

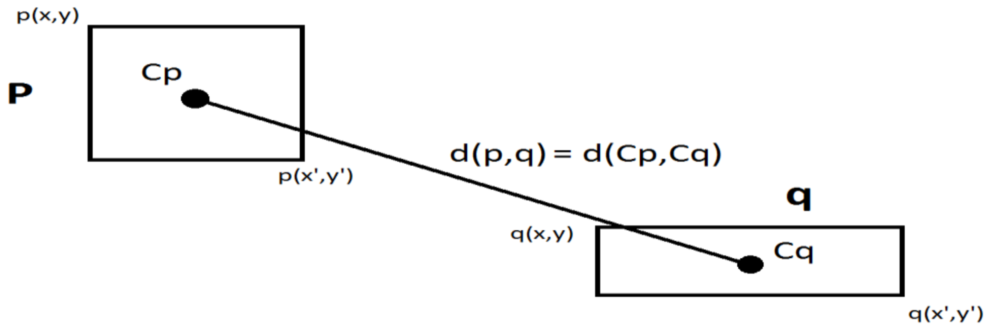
The agglomerative clustering algorithm starts each vertex (bounding box) as a singleton (or a cluster), and then iteratively merges similar clusters together in pairs, and stops when the desired number of clusters is achieved, or when another stopping criterion is achieved [Chen et al., 2010]. To implement this algorithm, the following two questions should be answered:

- how can the similarity (or dissimilarity) between the graph vertices be estimated?
- in each iteration, what is the vertex to be chosen in order to be grouped with another vertex for constructing a new cluster?

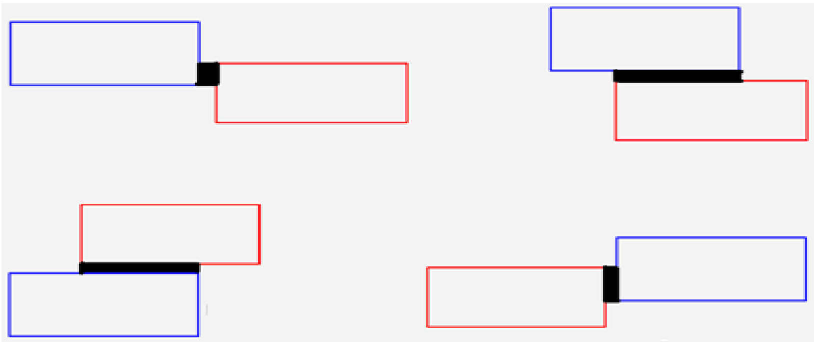
Two concepts of Gestalt theory (section 4.2) have been chosen to aid answering these two questions. Similarity (in size) and proximity (close edges) are two of many grouping concepts in classic Gestalt theory.

Concerning the first question, similarity of web page segments is estimated depending on the closeness measure between the segments. The closeness here depends on the geometric distance between the segments. The chosen distance is the Euclidean distance between the centroids of segments. Centroid of a segment is the center of the bounding box that represents it. For example, in figure 4.13(a), the rectangles p and q represent two segments. The distance d(p,q) between p and q equals the distance between their centroids Cp and Cq.

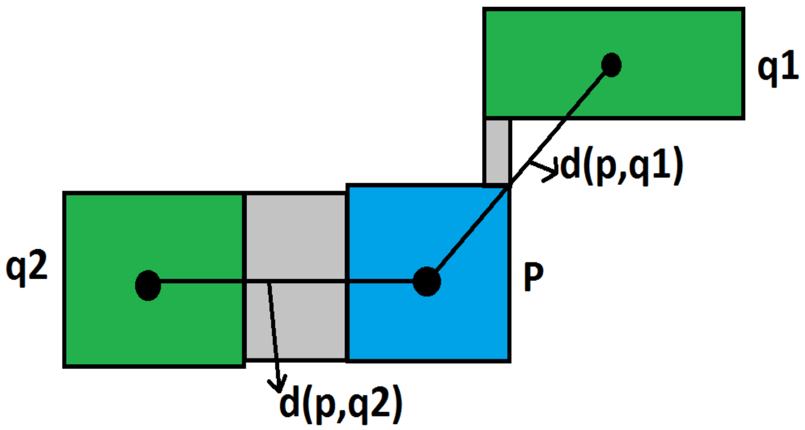
In case of equality of distance between a segment and other two segments, the criterion of common surface is applied (the more the segments have a common surface, the more it is possible to group them together. Figure 4.13(b) presents some examples of common surfaces between segments. Figure 4.13(c) presents an example of applying the criterion of common surface between two segments. In this example, the distance d(p,q1) is equal to the distance d(p,q2), but the common surface between the segments p and q2 is larger than the common surface between the segments p and q1, so the segment q2 is preferred to be grouped to the segment p more than the segment q1.



(a) Geometric distance between segments



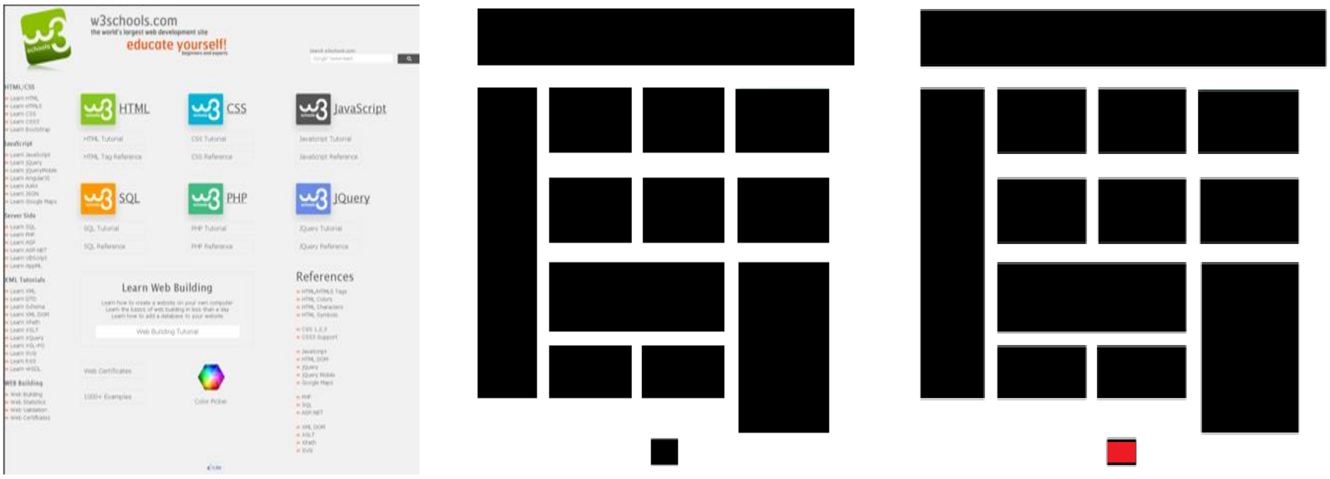
(b) Examples of common surfaces between segments



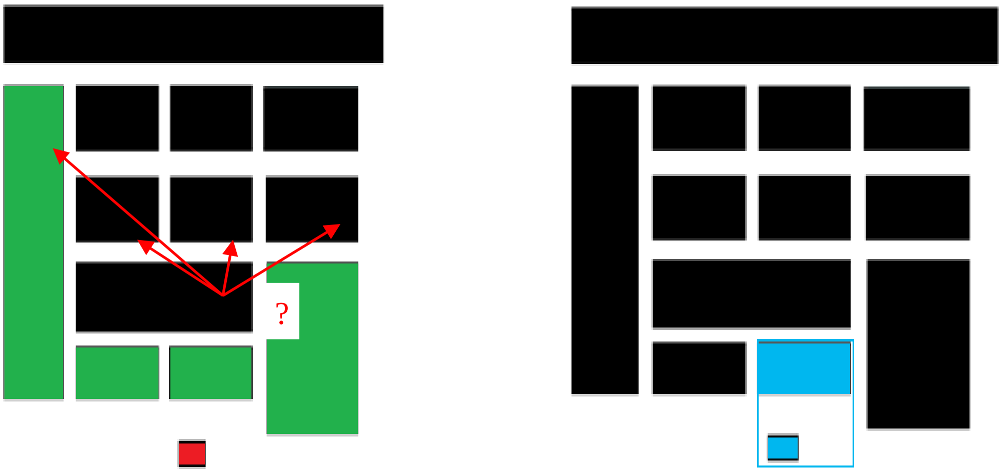
(c) An example of applying the criterion of common surface between two segments

Figure 4.13 Euclidean distance between the centers of objects, and the criterion of common surfaces.

In what concerns the second question, the smallest vertex in size is the vertex to be chosen in order to be grouped with another vertex for constructing a new cluster. This option has been chosen in order to preserve the visual structure of the segments. Figure 4.14 views an example of representing 13 segments (figure 4.14(b)) of the home page of site www.w3schools.com (figure 4.14(a)), how to select the smallest segment in size (red rectangle in figure 4.14(c)), and how to choose the most closed segment (figure 4.14(d) and figure 4.14(e)).



(a) Home page (b) 13 Segments (c) Smallest segment



(c) 4 options are possible group in (d) Grouping with the closest segment

Figure 4.14 An example of applying similarity and proximity criteria for grouping segments.

The DOM-tree obtained from the two first phases has been transformed to a graph, and an agglomerative graph-based clustering algorithm called "Blocks2Zones Clustering" was applied on the result graph. The pseudo-code of the proposed algorithm is:

Blocks2Zones Clustering Algorithm
Input (Blocks, n° of desired Zones)
Output: Graph of n nodes (n Zones)
1- Transform the blocks into a graph (Un-Directed graph)
1.1. Blocks → Nodes,
1.2. Make relations between the nodes, and assign weights for these relations.
2- If number of zones <= number of blocks
end the algorithm,
Else
3- Repeat till number of node s == number of desired zones
3-1 Find the node with the smallest size (node A)
(size of node ==size of the rectangle bounds the node)
3-2 For node A, find the closest node (node B).
3-3 Group the nodes A, and B (A+B) in one node.

Figure 4.15 views an example of applying the clustering algorithm to group the blocks of the home page of site www.w3schools.com to 4 zones (4 clusters).

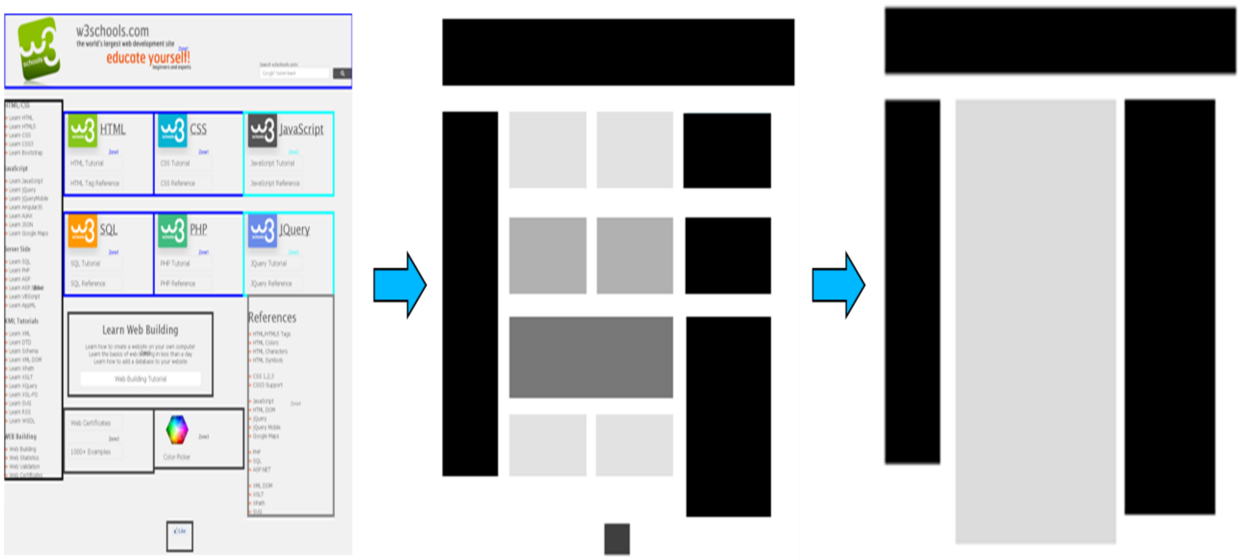
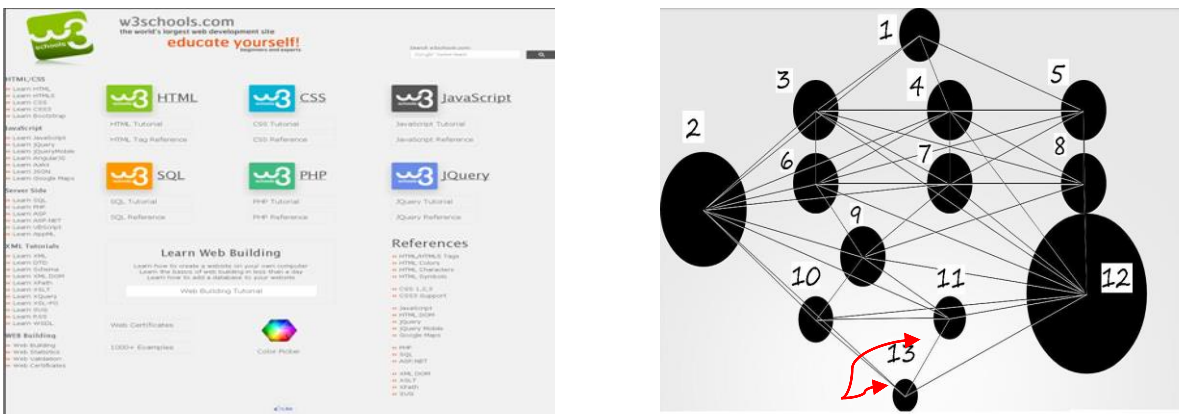


Figure 4.15 Clustering the contents of home page of www.w3schools.com to 4 zones.

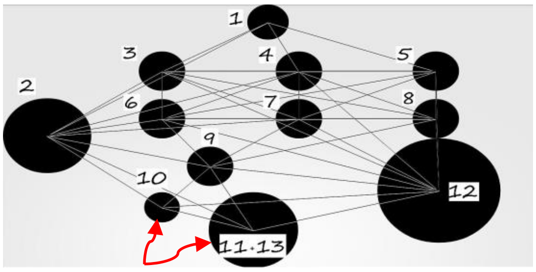
The output graph is described as following: G = (V, E), where G is undirected graph, V is a set of vertices (nodes or zones), and E is a set of edges (connections between zones), and |V|=n (number of desired zones). The set of vertices is defined as V={v_i: 1≤i≤n, vi is set of sub-zones}. The set of connections is defined as following E={ej: ej(v_{j1},v_{j2}) : v_{j1}∈V, and v_{j2}∈V}. To calculate the distance between nodes, the Euclidean distance has been used as following:

$$d(p,q) = \sqrt{(p_x - q_x)^2 + \left(p_y - q_y\right)^2}$$

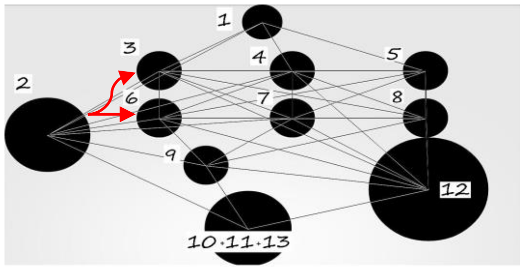
Where p and q are centroids of two nodes (centroid of a node is the center of the rectangle which bounds the node). In figure 4.16, an example of applying this algorithm on the home page of the site w3schools.com is given. In this example, the algorithm clusters the main page segments into 7 zones. The first iteration of the algorithm divides the page into 13 zones (because there are 13 main nodes in the DOM structure) and constructs a graph of 13 nodes.



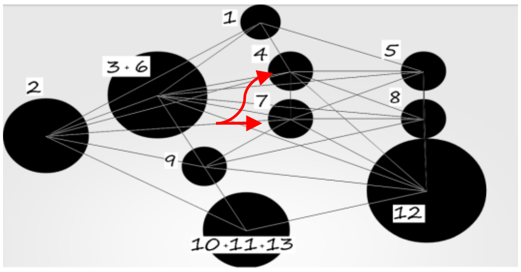
(a) Home page of www.w3schools.com (b) Constructed Graph (13 nodes)



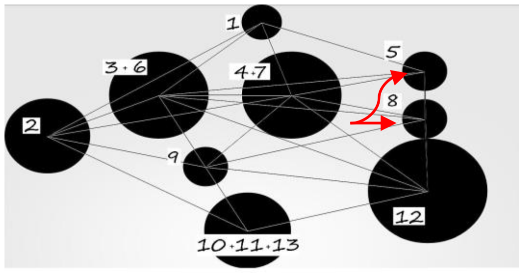
(c) A graph of 12 zones



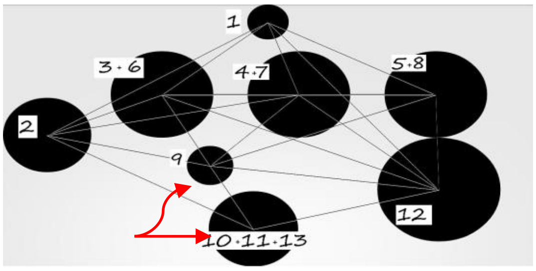
(d) A graph of 11 zones



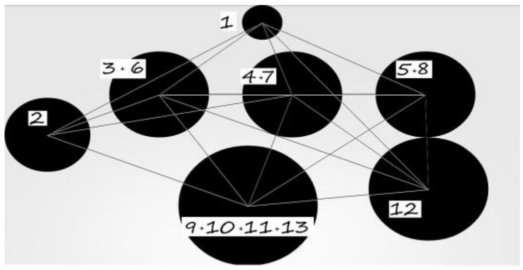
(e) A graph of 10 zones



(f) A graph of 9 zones



(g) A graph of 8 zones



(h) A graph of 7 zones

Figure 4.16 Clustering the home page of site www.w3schools.com into 7 zones.

Applying this hybrid segmentation algorithm on a filtered DOM-tree (obtained from applying Vision-based approach and DOM-based approach) converts a web page into a set of zones, each zone contains many other zones or blocks, since each block represents a visual structure of HTML element and may contain many other blocks. The purpose of the proposed vibro-tactile access protocol is then to transform semantics of symbols in these zones, or blocks, or HTML elements into vibrations with different frequencies and amplitudes.

4.3.3 Manual and automatic web page segmentation differences

In order to evaluate the suggested algorithm, and to know how sighted users understand web layout structures based on their visual perception, an experiment has been performed with the following protocol: 15 volunteers have been asked to segment manually different kinds of web pages. The volunteers were of different ages (between 25 and 50 years old), and most of them were informatics specialists. For each volunteer, 32 printed copies have been presented; the copies were A4 sized papers. 4 copies for each web page of 8 chosen web pages (2 pages from www.cdiscount.com, 2 pages from www.photobox.com, 2 pages from www.rueducommerce.fr, 1 page from www.w3schools.com, and 1 page from www.leparisien.fr). Each volunteer has been asked to segment the 4 copies of each web page into 3, 4, 5 and 6 zones with following considerations and criteria:

→ all the pages were printed in gray scale in order to avoid affecting the colors on the segmentation process. This option has been chosen because the current version of the suggested algorithm does not

support segmenting blocks depending on color variances,
→ users can segment the page using polygons with minimum of 4 points (triangles are not allowed),
→ users can start segmenting from any part or direction of the page (left, right, top, down, or center),
→ users have been asked to write the ordering number of zones (inside or beside the zone) while they make the segmentation process; this is very useful to know how the users start segmenting the pages, and how they end it.

After collecting all manual segmented copies (480 papers: 15 users x 8 web pages x 4 copies), the following observations have been noticed:
→ 70% of users did not start the segmentation process for certain number of zones at the same segment they start segmentation for other numbers of zones,
→ 16% of papers have been segmented starting from the center of the page, 3.5% have been segmented starting from the bottom of the page, and the majority of papers 80.5% have been segmented starting from top of the pages,
→ 20% of papers have been segmented vertically and 80 have been segmented horizontally,
→ 92.6% of segments are rectangles, and 7.4% of segments are polygons with more than 4 points.

To conclude the observations of this experiment: "it was very difficult to detect a segmentation method common between all users. Each user segments the pages depending on his/her understanding of the web page layout structure, on his/her visual perception of the visible elements, and on his/her interests and visual experience" [Safi et al., 2014a] [Safi et al., 2015a] [Safi et al., 2015b].

More results of this comparison are detailed in Appendix B.

4.3.4 Conclusion and drawbacks of the suggested algorithm

In this section, the main algorithm for segmenting and clustering web page HTML elements has been presented. The algorithm segments a web page into a preselected number of zones. Transforming the semantic of contents of each zone into vibration mode will be discussed in details in next chapters. The current version of the suggested algorithm has some drawbacks such:

- dealing with tables and lists of items (<ul> and <ol>) as a single block regardless their contents;
- the algorithm does not support a wide range of similarity features such similarity of color of segments, or semantic similarities between the textual contents of segments;
- the algorithm does not support some advances web techniques such as AJAX for websites which can be updated frequently.
- the considered distance between two segments is the Euclidean distance between their centroids. The algorithm does not support any another type of distances such minimum and maximum distances between the edges of segments (cf. figure 4.17).

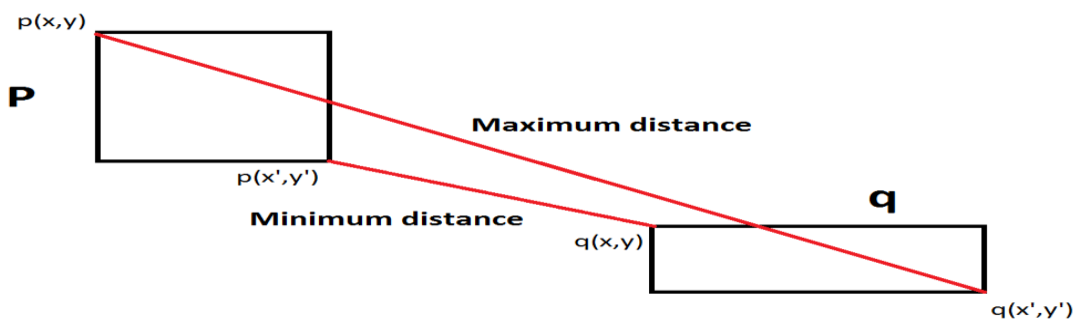
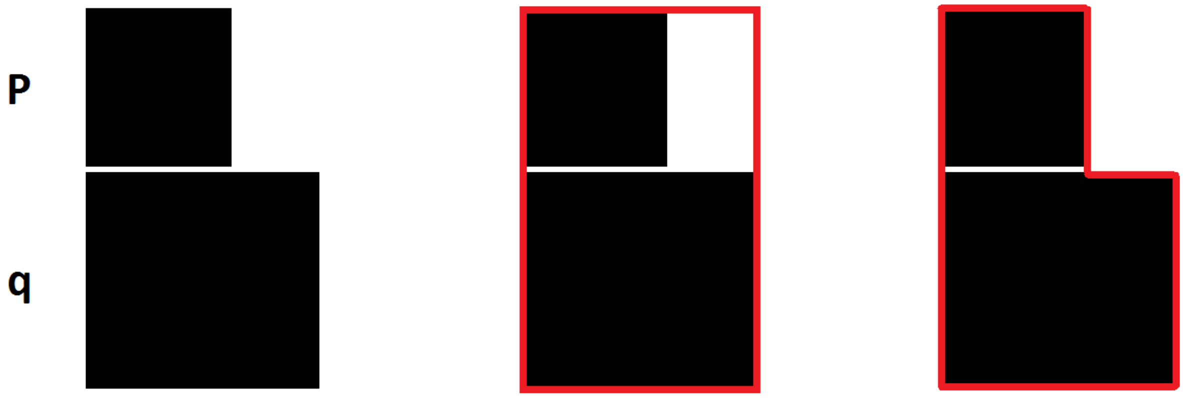


Figure 4.17 Minimum and maximum distances between two segments.

- the grouping of two segments is always a rectangle, and this is different sometimes of the real grouping results. Figure 4.18 presents an example of the difference between the algorithm grouping result and the real grouping result. This problem of planar union of rectangles is known in the domain of Computational Geometry [Monterde et al., 2014] [Schmid et al., 2004].



(a) Two segments grouping (b) Algorithm grouping (c) Real grouping

Figure 4.18 The difference between the algorithm grouping result and the real grouping result.

4.4 Web pages corpus (Economy - News - Tourism)

ART-ADN corpus is a web corpus that contains three types of French-language web pages: e-commerce, news, and touristic. The corpus was constructed and analyzed between January 2015 and June 2015.

4.4.1 Objectives of constructing the corpus

Evaluating TactiNET framework either with sighted or blind users is time-constrained, one hour or two hours at maximum of experiments with each person, in order to avoid the physical and mental tiredness from the side of the users, and to guarantee that the experiments are done in best cognitive conditions. In addition, the users are not available for long times.

During each time-limited experiment the psychological experimenter should evaluate many arguments and configurations for each evaluated web page. The main questions to be answered before running the experiments:
1) what are the web pages to be evaluated?
2) what are the accessibility and technological properties of the collection of evaluated web pages?
3) what are the best vibration configurations for each evaluated web page?

The third question will be answered next chapters in details. For the first two questions, the chosen methodology is:
1) constructing a web corpus that contains a collection of three categories of web pages: touristic, e-commerce, and news;
2) analyzing the accessibility and technological properties of the corpus; and
3) extracting one web page representative for each category. In this way, the psychological experimenter can evaluate (with many parameters and configurations) only one web page for each category, with respecting the conditions of times.

4.4.2 Constructing the corpus

100 web sites have been chosen for each type e-commerce, news, and touristic. The chosen e-commerce web sites are the top 100 French e-commerce navigated in 2014 [Top-100-ecommerce-francais, 2015], depending on statistics performed by www.ecommercemag.fr. 100 French-language touristic web sites and 100 French-language news web sites have been chosen. Some of them are

French national sites, and other touristic and news sites are international with a French-language version. The chosen 100 news web sites contain news journals, magazines, and TV web sites. For each web site, the home page (index page, front page, main page) address has been chosen and 2 non-homepage addresses have been chosen randomly. The total number of collected pages is 900 as presented in table 4.1. Appendix C presents a list of sites used to construct the corpus.

Table 4.1 Types and numbers of collected web pages.

Type of the web page	e-commerce	News	touristic	Total
N° of Home pages	100	100	100	300
N° of Non-Home pages	200	200	200	600
Total	300	300	300	900

As already described, the web service designed and implemented by the company SemioTime [Semiotime, 2016] has been used to get detailed information for these 900 web pages. The input for this web service is a URL address, and the tool supports an image in PNG format (Portable Network Graphics), an enriched HTML, and SVG (Scalable Vector Graphics) version of the web page. The total size of the collected files is 2.2 Go (Giga Octets).

4.4.3 Web accessibility properties

To study the web accessibility properties of the collected web pages, the web accessibility evaluation tool WAVE (Web accessibility evaluation tool) [wave-webaim, 2016] supported by the international World Wide Web consortium (W3C) [W3C, 2016] has been used. This on-line tool verifies the accessibility errors in a web page. Its input is a URL address of a web page, and its output is a plain text of accessibility errors. Evaluating the accessibility properties of a web page is useful in measuring its quality level, and in evaluating its accessibility complexity.

The accessibility errors found in ART-ADN corpus are:

- **Image missing alternative text** (Image alternative text is not present. Each image must have an "alt" attribute. Without alternative text, the content of an image will not be available to screen reader users [wave-webaim, 2016]);
- **Blinking content** (Blinking content is present. Blinking content can be distracting and confusing to users, particularly those with certain cognitive disabilities [wave-webaim, 2016]);
- **Document language missing** (The language of the document is not identified. Identifying the language of the page allows screen readers to read the content in the appropriate language. It also facilitates automatic translation of content [wave-webaim, 2016]);
- **Empty heading** (No content in the heading. Some users, especially keyboard and screen reader users, often navigate by heading elements. An empty heading will present no information and may introduce confusion [wave-webaim, 2016]);
- **Page refreshes or redirects** (The page is set to automatically change location or refresh using a meta tag. Pages that automatically change location or refresh pose significant usability issues, particularly for screen reader and keyboard users [wave-webaim, 2016]);
- **Empty button** (A button is empty or has no value text. When navigating to a button, descriptive text must be presented to screen reader users to indicate the function of the button [wave-webaim, 2016]);
- **Missing or uninformative page title** (The page title is missing or not descriptive. A descriptive title helps users understand a page purpose or content. Without a proper title, many screen readers' users may have difficulty orienting themselves to the page. [wave-webaim, 2016]);
- **Empty table header** (A "th" (table header) contains no text. The "th" element helps associate table cells with the correct row/column headers. A "th" that contains no text may result in cells with missing or incorrect header information [wave-webaim, 2016]);

- **Multiple form labels** (A form control has more than one label associated with it. A form control should have at most one associated label element. If more than one label element is associated to the control, screen readers may not read the appropriate label [wave-webaim, 2016]);
- **Image button missing alternative text** (Alternative text is not present for a form image button. Image buttons provide important functionality that must be presented in an alternative text. Without alternative text, the function of an image button is not made available to screen reader users or when images are disabled or unavailable [wave-webaim, 2016]);
- **Missing form label** (A form control does not have a corresponding label. If a form control does not have a properly associated text label, the function or purpose of that form control may not be presented to screen reader users. Form labels also provide visible descriptions and larger clickable targets for form controls [wave-webaim, 2016]);
- **Empty link** (A link contains no text. If a link contains no text, the function or purpose of the link will not be presented to the user. This can introduce confusion for keyboard and screen reader users [wave-webaim, 2016]);
- **Invalid long-desc** (The long-desc attribute is not a URL. The long-desc attribute of an image must be a valid URL of a page that contains a description of the image content. A long-desc value that contains image description text will not provide any accessibility information [wave-webaim, 2016]);
- **Broken skip link** (A skip navigation link exists, but the target for the link does not exist or the link is not keyboard accessible. A link to jump over navigation or jump to the main content of the page assists keyboard users only if the link is properly functioning and is keyboard accessible [wave-webaim, 2016]);
- **Marquee** (A marquee element is present. A marquee element presents scrolling text that the user cannot stop. Scrolling animated content can be distracting and confusing to users, particularly for those with certain cognitive disabilities [wave-webaim, 2016]).

After analyzing the accessibility errors, it was found that touristic pages contain a minimum number of accessibility errors, and news pages contain the maximum number of accessibility errors. The average value of accessibility errors per web page is 30.75 as presented in table 4.2.

Table 4.2 Numbers of accessibility errors in the collected web pages.

Type of the web page	**e-commerce**	**news**	**touristic**	**ART-ADN corpus**
N° of accessibility errors	9262	**11420 (Max)**	**6997 (Min)**	27679
Average of accessibility errors /page	30.87	38.07	23.32	30.75

Figure 4.19 presents the average number of accessibility errors in ART-ADN corpus for each type of errors. In this figure, the most repeated errors are image missing alternative text (18.13 errors per page); empty link (7.5 errors per page); and missing form label (2.82 errors per page).

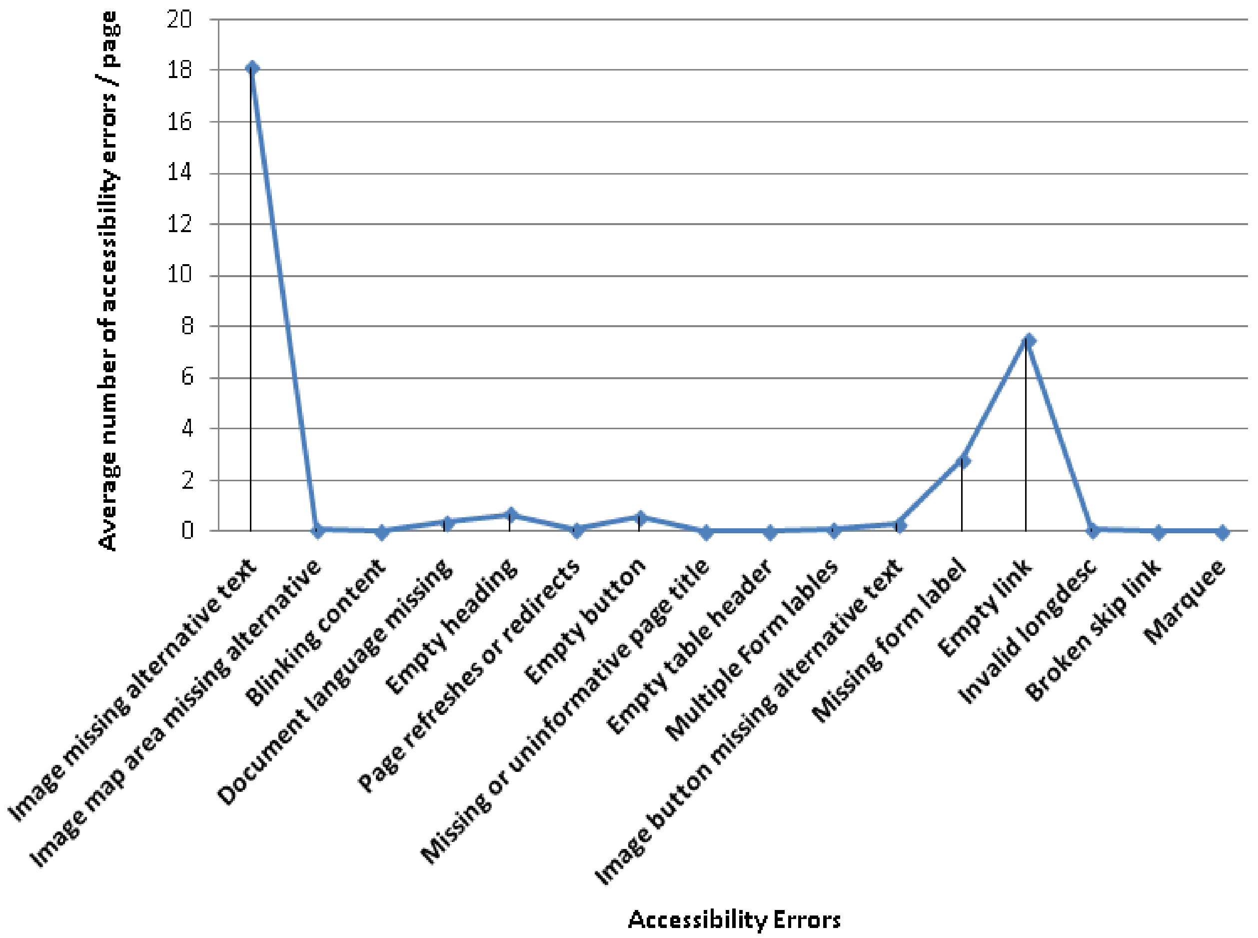


Figure 4.19 Average number of accessibility errors in ART-ADN corpus.

The average numbers of accessibility errors in home pages and in non-home pages have been studied for the three categories (e-commerce, news, and touristic) in the corpus, in order to view if there is a significant difference in accessibility errors between home pages and non-home pages. As presented in table 4.3, home pages have a little more accessibility errors (33.53 errors per home page) than non-home pages (29.37 errors per non-home page). For the touristic and e-commerce pages, there is no significant difference in average numbers of accessibility errors in home and non-home pages. But for the news category, there is a significant difference in average numbers of accessibility errors in home pages (45.62) and non-home pages (34.29).

Table 4.3 Average numbers of accessibility home and non-home pages.

Type of the web page	**e-commerce**	**news**	**touristic**	**ART-ADN corpus**
Average number of accessibility errors per home page	31.69	**45.62**	23.29	**33.53**
Average number of accessibility errors per non-home page	30.465	**34.29**	23.34	**29.37**

4.4.4 Technological Properties

To explore and evaluate the constructed corpus, the technological properties for each web page have been analyzed. Studying the technological properties for a web page aids more and more to evaluate its level of technological complexity, and this may give more understanding of its visual structure complexity (researches indicated a relation between the technologies in a web page and its visual complexity [Harper et al., 2013]), especially when relating between these technological properties and those of the accessibility properties.

The analyzed technological features are:

- **frameworks** (PHP, Perl, J2EE...);
- **JavaScript libraries** (client-side scripts embedded in HTML web pages and interact with the document object model (DOM) of the page);
- **widgets** (third party web components that are developed for one or more different software platforms, such as the re-usable icons of social sites);
- **aggregation functionality** (standard web feed formats that are used to publish frequently updated information such as RSS (Rich Site Summary));
- **advertising networks** (components support online advertising)
- **encoding** (such as UTF-8);
- **markup languages** (XHTML and HTML);
- **image file formats** (such as PNG (Portable Network Graphics), and Bmp (Bitmap images));
- **content language** (French); and
- **content management systems** CMS (tools support creation and modification of digital contents using common user interfaces).

The following sites: http://builtwith.com/ and http://w3techs.com/sites have been used to study the technological properties. These tools are online web interfaces, where the user enters a target website URL, and each tool supports the user by a list of used technologies in the target website. Another tool has been used also, wappalyzer [(1)] which is a browser extension to be integrated with a web browser.

Figure 4.20 presents the frameworks used in designing the web pages included in ART-ADN corpus.

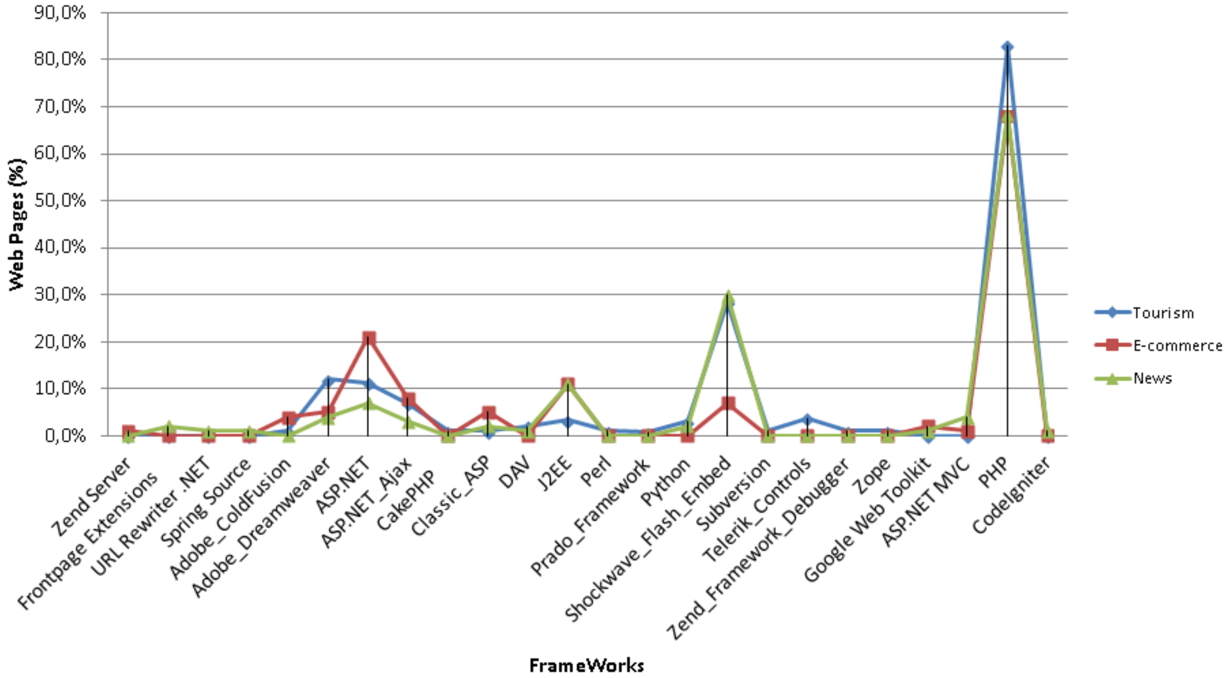


Figure 4.20 Frameworks used in constructing and designing the ART-ADN corpus.

(1) https://wappalyzer.com [Access 07/01/2016]

As presented in figure 4.20, it is noticeable that a large number of sites (about 73%) included in ART-ADN corpus use the scripting language PHP. About 30% of touristic and news web sites use the framework Shockwave-Flash-Embed that generates flash-based sites, and about 9% of e-commerce and touristic web sites use the framework ASP.NET_AJAX that generates dynamic client-server interactions without requiring pages to be reloaded or refreshed. These percentages are coherent with researches indicates that using Flash media files and AJAX techniques causes a lot of accessibility errors for blind persons while navigating the Web [Webaim_screenreadersurvey, 2009].

After analyzing the used JavaScript libraries, it was found that the average number of using JavaScript libraries per page is 6.083. The most used library is JQuery [Jquery, 2016]. This result is coherent with studies indicated that using Java scripts causes a lot of accessibility errors for blind persons while navigating the Web [Webaim_screenreadersurvey, 2009].

Encodings used in the corpus are UTF-8 (84.55% of pages); ISO/IEC 8859 (18.89% of pages); and Windows-1252 (2% of pages). Some pages use more than one encodings (in this case, the web page is divided into many frames, and there is a coding style for each frame).

Markup languages used in the corpus web pages are HTML (57.66% of pages) and XHTML (49.22). Image files formats used are JPEG (Joint Photographic Experts Group), PNG (Portable Network Graphics), SVG (Scalable Vector Graphics), BMP (Bitmaps), GIF (Graphics Interchange Format). 94.67% of sites use JPEG images, 91.44% of sites use PNG images, 5% of sites use SVG images, 1% of sites use BMP images, and 66.56% of sites use GIF images.

Table 4.4 presents some statistics about the widgets, aggregation functionalities, and the advertising networks used in the web pages of ART-ADN corpus.

Table 4.4 Statistical information about the widgets, aggregation functionalities, and the advertising networks used in ART-ADN corpus

Technology Type	Average number of using the technology per web page in ART-ADN corpus	Most common used technology in ART-ADN corpus (percentage of web pages use this technology)
Widgets	2.89 widgets per web page	"Facebook Like" (31.11%)
Aggregation Functionality	0.503 aggregation functionality libraries per web page	"RSS" (34.06%)
Advertising Networks	5.672 advertising networks per web page	"DoubleClick.Net" (58.11%)

Concerning the CMS tools (Content Management Systems) used to create web pages of ART-ADN corpus. 33.2% of sites use CMS tools to construct the contents. The most used tool is Drupal (www.drupal.org), where 10.9% of sites use it to construct the contents.

Figure 4.21 presents percentages of using CMS tools for each category. Drupal is the most used CMS in news category, where 17% of news sites use it to construct the contents. PrestaShop (www.prestashop.com) is the most used CMS in e-commerce category (6% of sites e-commerce sites use it). Drupal and ez-systems (www.ez.no/) are the most used CMS in touristic category (13.7% of touristic sites use Drupal, and 13.7% of touristic sites use ez-systems).

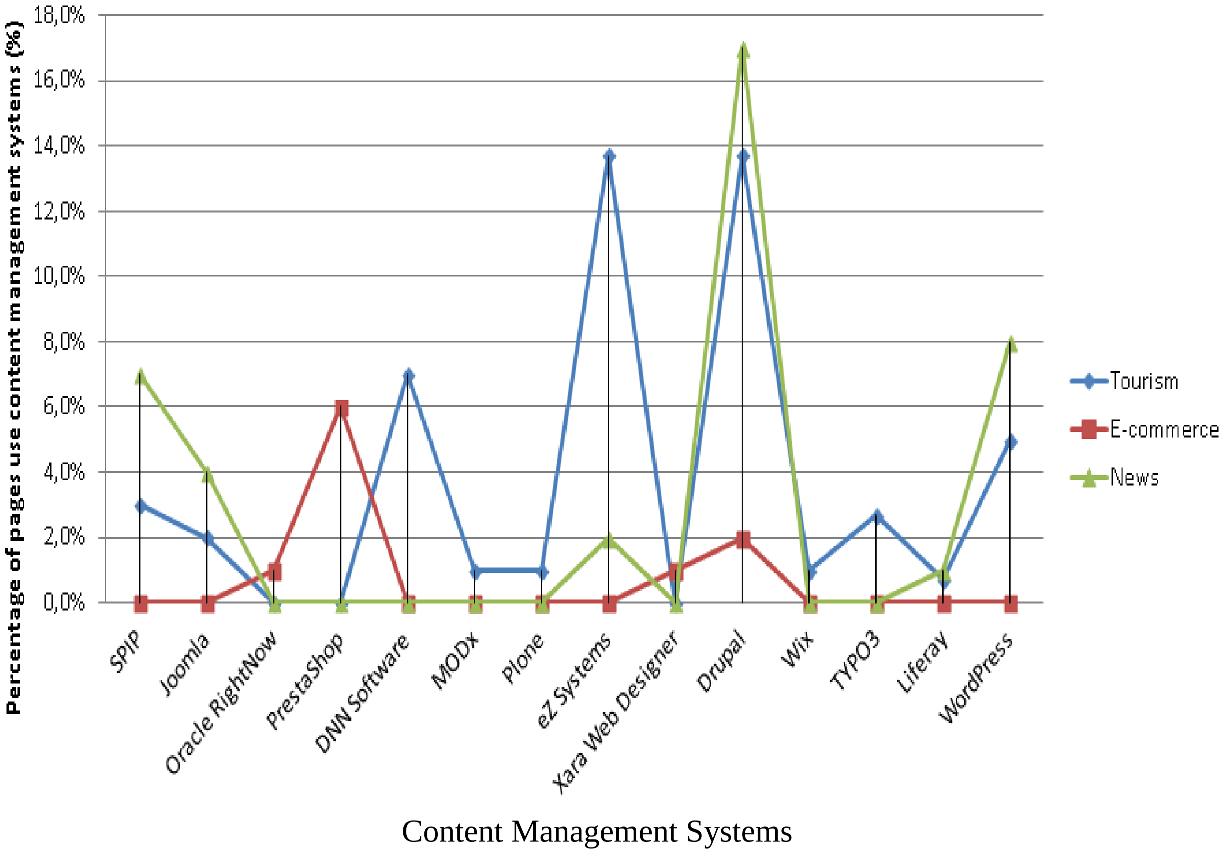


Figure 4.21 Using content management systems in ART-ADN corpus web pages.

To conclude a relation between the used technologies and the accessibility errors in web pages, the average number of technological libraries and components per page has been calculated for each category. Figure 4.22 presents a comparison between the used technologies and the accessibility errors.

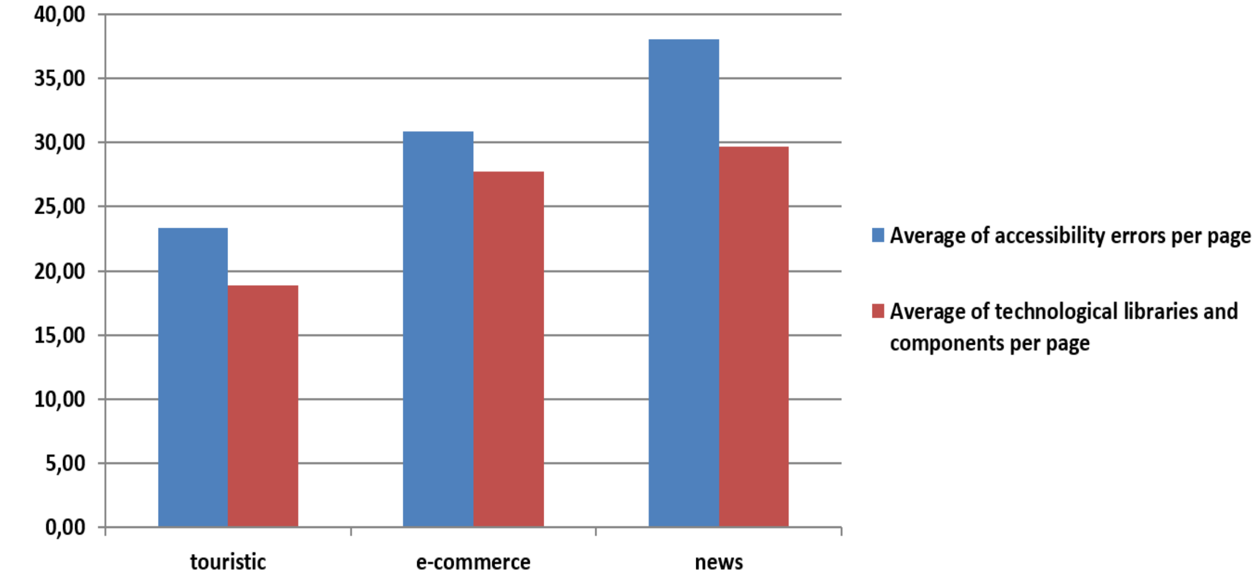


Figure 4.22 The comparison between the average number of the technologies and the accessibility errors in ART-ADN corpus.

As presented in figure 4.22, the news web sites have more accessibility errors than e-commerce and tourism, and also news web sites use more technological libraries and components than other categories. Touristic web sites have less accessibility errors than news and tourism, and also touristic web sites use technological libraries and components less than other categories.

By analyzing the relation between technological and accessibility properties (figure 4.25), the following can be concluded: "in web sites, the more the site contains technologies, the more it contains accessibility errors". This conclusion shows a coherence with other studies indicate that there is a correlation between web pages complexity and accessibility, so that "the more the web page is complex, the less it is accessible" [Lopes et al., 2010].

4.5 Extraction of categories representatives

As presented previously, evaluating TactiNET framework is time-constrained. So extracting a web page representative for each category in the corpus is fundamental step for optimal experiment conditions. In this section, the methodology and the results of extracting web pages representatives are introduced.

4.5.1 Methodology of extracting web pages representatives

A representative (or common template) for a set of web pages is a web page most similar with other web pages in the same set. Many approaches have been proposed to measure the similarity between two web pages. Some approaches measure the similarity between textual contents [Cohen, 1999] [Friburger et al., 2002] [Broder et al, 1997]. Other approaches depend on the hyperlink structure of web pages to calculate the similarity between two web pages [Dean et al., 1999] [Halkidi et al., 2003]. The structural layout of the pages is a factor of measuring the similarity for many other approaches [Cruz et al., 1998] [Joshi et al., 2003] [Zhang et al., 2012].

In this work, a web page spatial layout similarity approach has been chosen [Zhang et al., 2012]. This approach first extracts the spatial layout features from a given web page as rectangle blocks (bounding boxes of HTML elements), and measures the similarity between two web pages depending on their spatial layout characteristics. This approach has been chosen because its idea is very close to the segmentation method proposed in section 5.3.

The methodology of extracting the web pages representatives for each category in ART-ADN corpus is as following:

- collecting together the enriched web pages for each category (300 web pages for each category e-commerce, news, and tourism). Each web page contains bounding boxing information for each of its HTML elements;
- for each web page, calculate the intersected points (pixels) between the bounding boxes of its elements and the bounding boxes of elements in other web pages in the same category (figure 4.23);
- for each web page in each category, sum the number of intersected points with other web pages in the same category (figure 4.24);
- for each category, choose the web page representative that has the most intersected points with other pages.

Figure 4.23 represents an example of calculating the intersection points between two bounding boxes A and B. In this figure, the result of intersecting the rectangles A and B is a new rectangle, its height is 130, and its width is 150, so the number of intersected pixels between the two rectangles is 19500 (130 x 150) pixels.

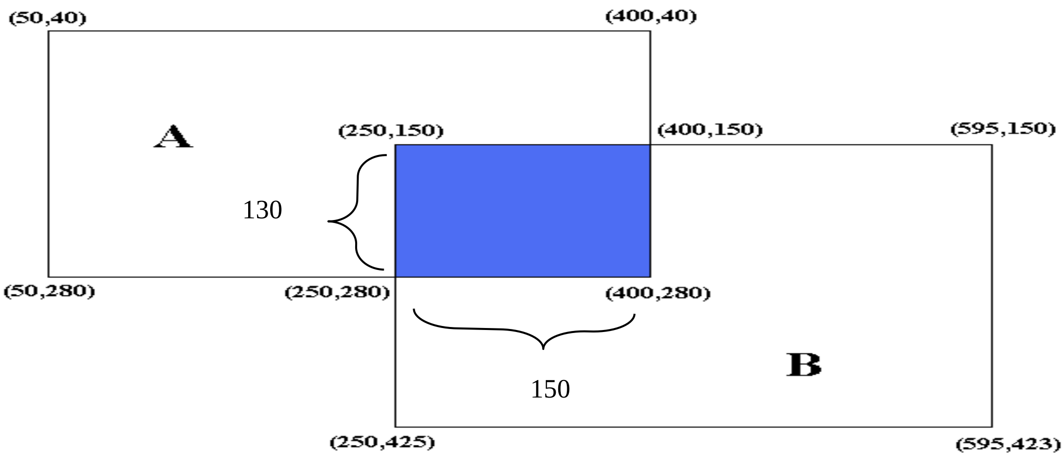


Figure 4.23 Calculating the intersection points between two bounding boxes.

Figure 4.24 presents the process of measuring the similarity of a web page with other web pages in the same category. Each line between two web pages represents a similarity relation.

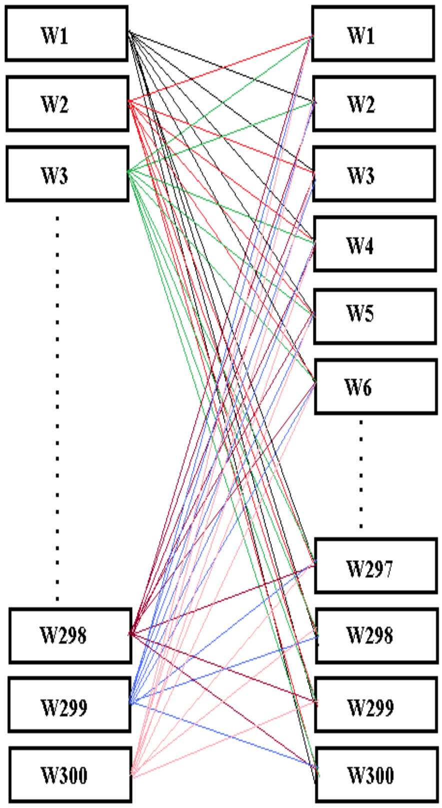
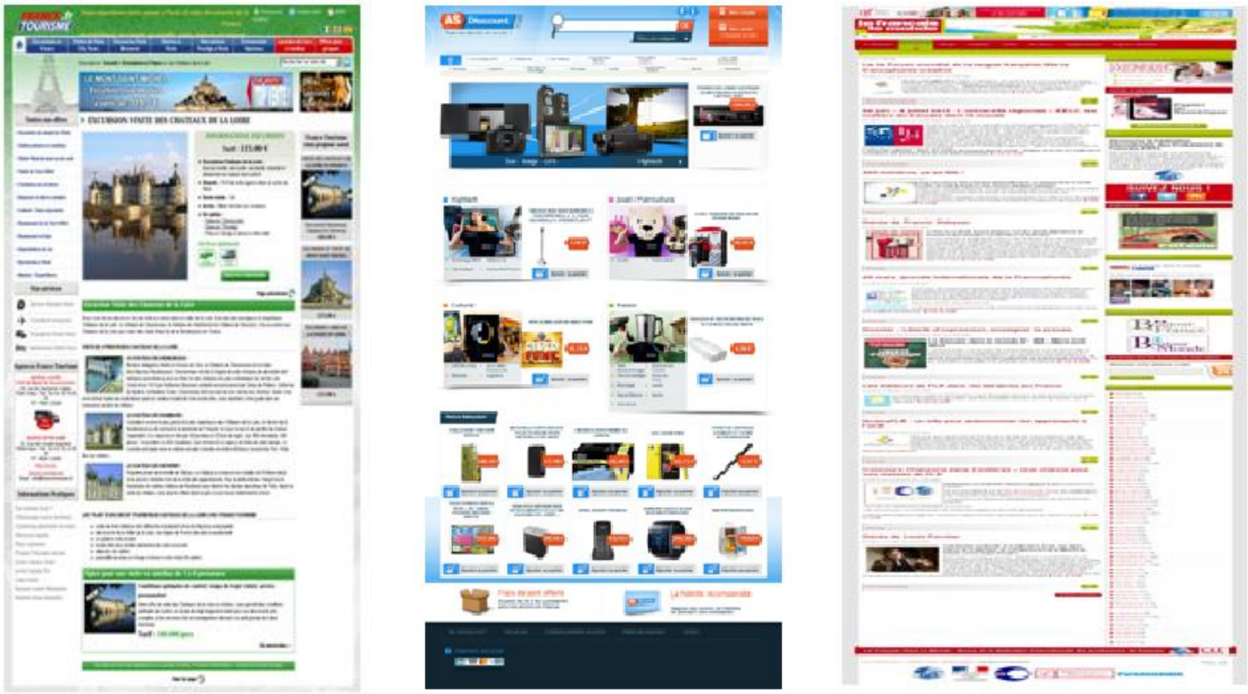


Figure 4.24 Measuring the similarity of a web page with other web pages in the same category.

4.5.2 Extracted representatives

After applying the similarity measures indicated in section 4.5.1, a web page representative in each category has been selected. The site www.francetourisme.fr is a representative of the touristic category (figure 4.25(a)). The site www.asdiscount.com is the representative of the e-commerce category (figure 4.25(b)). The site www.fdlm.org is the representative of the news category (figure 4.25(c)).



(a) www.francetourisme.fr
A representative of the touristic category

(b) www.asdiscount.com
A representative of the e-commerce category

(c) www.fdlm.org
A representative of the news category

Figure 4.25 Representatives of touristic, e-commerce, and news categories

4.6 Conclusion of Chapter 4

An agglomerative graph-based clustering algorithm of web page segments was presented in this chapter. This algorithm depends mainly on some grouping basics of Gestalt theory. A constructed web-based corpus was used to extract a web page representative for each of the three categories in the corpus. The three web pages representatives will be transformed into vibration format, and will be used to make psychological experiments with sighted and blind persons. Protocols and results of these experiments will be discussed in details in next chapters.

Chapter 5:
Basic Parameters and Arguments of the Graphical Vibro-tactile language

Résumé : La conception d'un langage graphique vibro-tactile est essentielle pour construire la TactiNET. Ses règles, principes et recommandations sont nécessaires pour gérer l'interaction tactile non visuelle entre personnes malvoyantes et les pages Web navigables. La modélisation de ces règles, principes et recommandations nécessite la sélection d'une série de valeurs et d'arguments pour la présentation des symboles graphiques (formulaires) et la génération des retours vibro-tactiles. Ce chapitre présente les expériences principales qui ont été exécutées pour sélectionner une série de valeurs et des arguments fondamentaux afin de concevoir le langage graphique vibro-tactile.

La première expérience exécutée vise à examiner la performance des personnes malvoyantes à reconnaitre des formes grâce à des retours vibro-tactiles. Les données de performance sont rapportées, y compris le nombre d'erreurs, et la compréhension qualitative des formes vibrantes affichées. La deuxième et la troisième expérience visent à sélectionner les plages de fréquences et les valeurs d'amplitude (respectivement) à utiliser pour générer les retours vibro-tactiles. Ces valeurs de fréquence et d'amplitude ont été utilisées pour représenter le contraste des éléments visuels dans chaque segment d'une page Web. Ce chapitre présente les détails de chacune de ces trois expériences. Le protocole d'exécution de chaque expérience, les résultats, et leur analyse sont présentés.

5.1 Introduction of Chapter 5

Designing a graphical vibro-tactile language is essential in TactiNET framework. Its rules, principles, and recommendations are necessary for managing the non-visual tactile interaction between visually impaired persons and the navigated web pages. Modeling these rules, principles, and recommendations requires selecting a series of values, and arguments for presenting the graphical symbols (forms), and for generating the vibro-tactile feedbacks. This chapter presents the main experiments that have been executed to select a series of values, and arguments that are fundamental for designing the graphical vibro-tactile language.

The first executed experiment aims to examine the performance of visually impaired people in recognizing shapes through vibro-tactile feedbacks. Performance data is reported, including number of errors, and qualitative understanding of the displayed shapes. The second and the third experiments aim to select frequency ranges and amplitude values (respectively) to be used in generating the vibro-tactile feedbacks. These values of frequency and amplitude have been used to represent the contrast of visual elements in each segment in a web page. This chapter introduces the details for each of these three experiments. The protocol of running each experiment, the results, and their analysis are presented.

5.2 First experiment: pre-tests for examining the performance in recognizing shapes through vibro-tactile feedbacks

5.2.1 Objective of the recognizing shapes experiment

The first experiment aims to examining the ability of visually impaired persons in recognizing shapes through vibro-tactile feedbacks. The experiment first had been conducted with 15 sighted users (their eyes were closed) to view the possibilities of the proposed device, and to prepare the experimental protocol with visually disabled people [Maurel et al., 2012] [Maurel et al., 2013]. Later, the experiment has been conducted with 5 blind persons. Testing the protocol with sighted and blind persons gave more understanding of tactics and strategies they follow to navigate the designed structures [Safi et al., 2014b] [Safi et al., 2015c].

The main idea of the first experiment is mapping different shades of gray scales for shapes presented on touch-screen mobile devices into tactile vibrations. The first prototype device of TactiNET was used to execute this experiment. The device was described in details in section 3.3 in the third chapter. This device is a wireless interface connected with two actuators. It controls the vibration intensity of the two actuators with a range of frequencies goes from 0Hz to 250Hz. During this experiment, only one actuator has been used.

A Bluetooth connection with an Android tablet allows controlling the vibration intensity (amplitude) of the active vibrator. An Android dedicated program displays an image on the tablet screen and detects the location where the user touches the tablet screen. The gray level of touched points is transmitted to the embedded device in order to control the vibration intensity. The tablet is a Samsung GALAXY Tab 2, 10.1 inch, and its dimensions' height, width, and depth are 175.3 mm, 256.7 mm, and 9.7 mm respectively [Samsung_galaxy_tab_2, 2016]. Its Android system version is 4.1.2.

5.2.2 Protocol of the recognizing shapes experiment

Each experiment (either for sighted or blind persons) consists of 4 ordered phases of training (learning task), and four ordered phases of evaluation (evaluation task). All the phases were filmed. Figure 5.1 presents the 4 patterns in the training phases, and figure 5.2 presents the 4 patterns in the evaluation phases.

Image a (training task) Images b (NT2), c (NT3), d (NTG)

Figure 5.1 Patterns of the training tasks.

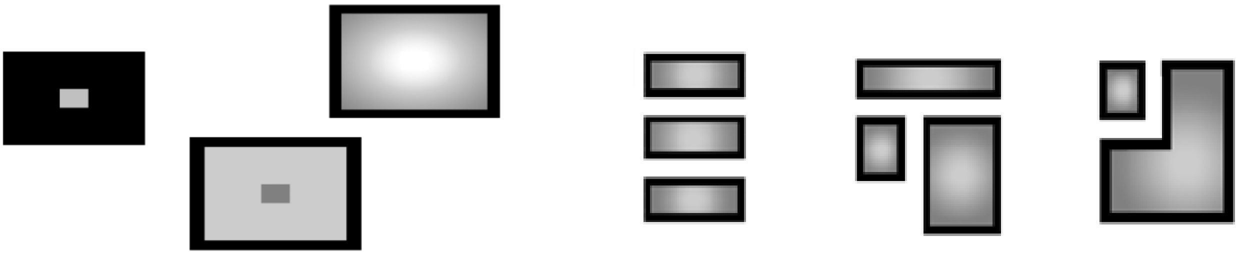


Image a (evaluation task) Images b (IDP1), c (IDP2), d (IDP3)

Figure 5.2 Patterns of evaluation tasks.

In the training task, each user discovers firstly the graphical elements in each image presented in figure 5.1 (images a, b (NT2), c (NT3), and d (NTG)). The names of the graphical elements were informed to the participants. The name of images NT2, NT3, and NTG indicate how many transitions are necessary to access the square center. The shape NT2 proposes 2 transitions to access the center of the shape. The shape NT3 shows three transitions. NTG presents a compromise shape with a gradient transition. The objective of designing the image NTG is to analyze the user reaction through a continuous decreasing (or increasing) of gray scales. This continuous changing in gray scales will generate continuous changing (decreasing or increasing) in the vibration intensity.

Designing the images NT2, NT3, NTG in this way supports more feedbacks on how the user reacts with different types of backgrounds and borders, and how the user moves his/her finger in the right direction to recognize the shapes. The main objective of the training task was to make the users more familiar with the device and with the tactile concepts of the experiment. In addition, it allows the users to feel the vibro-tactile perception relation before starting the evaluation task, and to perform different scanning speeds to choose the most suitable one.

The evaluation task consists of 4 phases; the first one allows the user to discover the image 5.2(a) and to name each shape inside it. The objective of this phase is to evaluate how the user would recognize some basic shapes already presented in the training session.

Next phases are more challenging and require more memorization efforts. These phases are about images 5.2(b), 5.2(c), and 5.2(d). Users have been asked to discover contents of each image, then to describe these contents, and to redraw the discovered elements inside each image.

The images have been designed manually, and they have been chosen depending on following considerations:

- Image 5.2(a) contains all squares on which users have been trained in the training task. This image tests the ability to memorize and to distinguish the trained shapes;
- Image 5.2(b) contains 3 rectangles with matched sizes and with vertical order. The image 5.2(c) contains 3 rectangles with different sizes and with many spatial relations. Testing

images 5.2(b), and 5.2(c) might test the ability of distinguishing sizes, directions, and distinguishing spatial relations;

- Image 5.2(d) contains different shapes (a rectangle and a polygon of 6 edges). Image 5.2(d) evaluates the ability to distinguish different shapes in the same image, and to distinguish spatial relations;
- The designed images contain examples of expected results of the segmentation process for web pages. So, success in distinguishing these shapes by blind users is an indicator of their ability to distinguish results of segmenting web pages.

5.2.3 Results of the recognizing shapes experiment with sighted persons

The experiment has been conducted with 15 sighted persons. Their eyes were closed. The duration with each participant ranged from 15 minutes to 36 minutes. The experiment with sighted persons has been conducted before starting the PhD [Maurel et al., 2012], and some of its results are indicated in this section due to its importance and correlation with the conducted experiments during the PhD period.

Table 5.1 presents some results of the experiment for images NT2, NT3, NTG, the time required to distinguish graphical elements and the total number of errors for the 15 sighted persons. The users have been asked to name the shapes in figure 5.2(a), and then the number of correct and incorrect answers for each shape has been evaluated [Maurel et al., 2012].

Table 5.1 Results of experiments with sighted persons for images NT2, NT3, and NTG [Maurel et al., 2012].

Shape Name	Average Time in Seconds	Number of Errors	Percentage of errors (of 15 users)
NT2	28	**2**	**13.33%**
NT3	36	6	40%
NTG	22	3	20%

The lowest number of errors is assigned to the image NT2 (13.33%), and the largest time period and max number of errors is assigned to the image NT3 (40%). A low number of errors has been also assigned to the image NTG (20%). One drawback during executing this task is that the time to recognize the shape was constrained. In particular, when the participant takes a time longer than 1 minute to recognize a shape, its answer will be considered wrong directly.

As a conclusion for the experiment conducted with sighted persons: black and gradient backgrounds (such images NT2 and NTG respectively) are effective for fast and approximate shape recognition.

5.2.4 Sequence of the recognizing shapes experiment with blind persons

The tests that were performed with 5 blind persons consisted of following:

- personal and technical questions;
- explanations of the experiment objective;
- a training task; and
- an evaluation task.

The approximated average time for each participant is about 1 hour. Before initiating the training and the evaluation phases with blind participants, the experimenter explained to the blind persons the idea, the objectives, and the phases of each task of the experiment. This phase was important to initiate the participants for accepting kindly the test and for motivating them to do their best.

5.2.4.1 Personal and technical questions

Before starting the tests with the 5 blind persons, they have been asked to support the experimenter with information about their ages and dates of their blindness. Table 5.2 summarizes their answers of personal questions.

Table 5.2 Personal information of the blind participants.

User-ID	ID0	ID1	ID2	ID3	ID4
Age (Years)	63	**67**	59	56	**36**
Sex	Male	Female	Male	Female	Female
Date of the blindness	since birth (congenital vision loss)	since 32 years (adventitious vision loss)	since 25 years (adventitious vision loss)	since 10 years (adventitious vision loss)	since 15 years (adventitious vision loss)

Participants have been also asked to provide some technical information about their experience in dealing with operating systems, screen readers, and what are the main problems when they navigate the Web. Table 5.3 shows a summary of answers for these technical questions. The first two columns represent the number of operating systems (either Windows or Linux) used either on fixed or portable computers. The third, fourth, and fifth columns indicate the number of users who use JAWS (Job Access With Speech), NVDA (NonVisual Desktop Access), and ORCA, either on fixed or portable computers.

Table 5.3 Used operating systems and screen readers.

	Windows	Linux	JAWS	NVDA	ORCA
Installed on fixed computers	**4**	0	**4**	2	0
Installed on portable computers	**2**	1	**2**	1	1

The majority of participants use the operating system Windows either on fixed or portable computers. The most used screen reader is JAWS. No one of the five blind persons uses a tablet, and the screen readers used with cellular phones are Talks and MobileSpeak with Nokia phones, and Voiceover with iPhone. Only one of the 5 participants uses a mobile device to access the Web (access via iPhone). The 5 participants reported the following main difficulties for accessing the Web via fixed or portable computers, or via iPhone mobiles:

- problems of access to Flash files, problems of AJAX technologies;
- inability to recognize the global structure of web sites.

5.2.4.2 Training task with blind persons

In this training task, the participants discovered the graphical elements in each image presented in figure 5.1 (images a, b (NT2), c (NT3), and d (NTG)). They were informed for each shape name. This task was very important for participants to test the system before the evaluation task, and to know exactly how the system transforms different levels of gray under the touched points into vibrations.

During this task, the dedicated Android program recorded the information about touched points in log files (X and Y coordinates, touch pressure, and period of navigation for each image). Table 5.4 indicates training times in minutes for each one of the 5 participants, and for each image in figure 5.1.

Table 5.4 Times of training task for each blind participant (in minutes).

User ID / Image	ID0	ID1	ID2	ID3	ID4	Total time	Average time
A	5	2,6	3,6	10	4	25,2	**5**
b (NT2)	4,4	3,1	1	3,3	1	12,8	2,6
c (NT3)	2,8	6,3	2,5	2,9	1,2	15,7	3,1
d (NTG)	3,1	4	2	3,2	1,3	13,6	2,7
Total	15,3	16	9,1	**19,4**	**7,5**		

It is noticeable in table 5.4 that discovering the first image (image a) takes more time, because it is the first experiment for blind users on this prototype. There is also a significant decrease in time between the first and last image in the training task. This might be an indicator that training the users decreases the time for discovering graphical elements. It is also noticeable that there are significant differences in times between the participants. For example, the user with ID4 needed 7.5 minutes to scan all the images (A, NT2, NT3, and NTG), while the user with ID3 needed 19.4 minutes to scan the same images.

5.2.4.3 Evaluation task with blind persons

This task consists of two phases. In the first phase, each user has been asked to discover the image 5.2(a) and to find how many shapes inside it, and to name each founded shape. In the second phase, each user has been asked to discover images 5.2(b) (IDP1), 5.2(c) (IDP2), and 5.2(d) (IDP3), and to answer some questions about the discovered shapes, then to redraw the discovered shapes.

Table 5.5 presents the answers for the first question about naming shapes in image 5.2(a). In table 5.5 and all next tables, the symbol ✓ represents a correct answer for the touched shape, and the symbol X represents an incorrect answer or inability to answer the question.

Table 5.5 Evaluating answers of the first question about naming shapes in image 6.2(a).

User-ID/ Shape name	ID0	ID1	ID2	ID3	ID4	Number of errors	Percentage of errors (of 5 users)
NT2	✓	✓	✓	X	✓	1	20%
NT3	✓	✓	X	X	✓	2	40%
NTG	✓	X	✓	X	✓	2	40%
Number of errors	0	1	1	3	0	5	

In table 5.5, the lowest number of errors is assigned to shape NT2, and it is the same result which has been obtained during tests with sighted persons. This result might be an indicator that less the shape has gradient transitions more it is recognizable.

Answers for questions related to images IDP1, IDP2, and IDP3 are summarized in table 5.6.

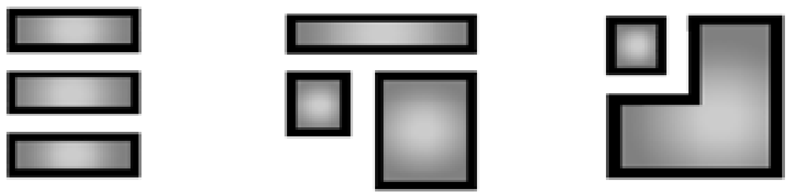
Table 5.6 Answers of questions about images IDP1, IDP2, and IDP3.

User-ID	ID0			ID1			ID2			ID3			ID4			Percentage of correct answers
Image IDP	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	
Answers about number of shapes in the image	✓	✓	X	✓	X	X	✓	X	✓	X	✓	✓	✓	✓	✓	66.66%
Answers about sizes of shapes in the image	X	X	X	X	X	X	✓	X	X	X	✓	✓	✓	✓	✓	40%

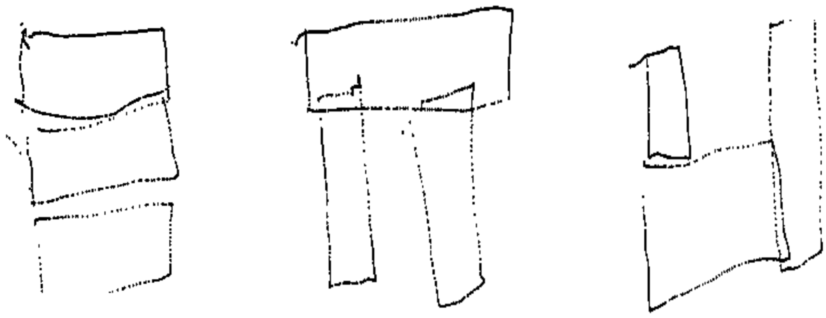
The first question about images IDP1, IDP2, and IDP3 was to select the number of shapes in each discovered image. The percentage of correct answers is 66.7% (10 corrects answers of total 15 answers). The second question was to select if the sizes of shapes in each image are equal or not. The percentage of correct answers is 40% (6 corrects answers of total 15 answers). These two percentages indicate that it is easier for blind persons to recognize the number of shapes more than recognizing the equality of shapes sizes.

It is noticeable from data in tables 5.4, 5.5, and 5.6, that the best performance is assigned for the user with ID4. This might be because that this female user is the youngest between others, and it might be because she was the only participant that has already used touched devices (an iPhone device supported by VoiceOver).

After answering questions about each image of images (IDP1, IDP2, IDP3), each participant has been asked to redraw the graphical elements founded in each touched image. Figure 5.3 views the original images and the redrawing results of the user with ID4 (the female user who supported best answers).



(a) Original images IDP1, IDP2, IDP3.



(b) Redrawing images IDP1, IDP2, IDP3 by user ID4.

Figure 5.3 Original and redrawing images IDP1, IDP2, IDP3 for the user ID4.

Comparing the original images with results of redrawing images presented in figure 5.3(b) concludes the following:

- an ability of distinguishing sizes of shapes, because the degree of scaling between redrawing shapes is nearly equal to the degree of scaling between real shapes (IDP1, IDP2, IDP3).
- an ability of distinguishing the spatial relations, because relations of directions (vertical order, left to, right to, etc.) between redrawing shapes is nearly equal to relations of directions between real shapes.

Times in minutes for the evaluation task are summarized in table 5.7.

Table 5.7 Times of the evaluation task for each participant (in minutes).

User ID / Image	ID0	ID1	ID2	ID3	ID4	Total	Average
a	1,23	9,87	5,39	7,84	1,85	26,17	5,23
IDP1	4,39	14,99	1,41	3,75	1,41	25,96	5,19
IDP2	7,70	9,22	0,79	1,99	13,85	33,55	6,71
IDP3	2,71	12,94	2,81	4,03	12,58	35,06	7,01
Total	16,03	47,02	10,39	17,61	29,68		

5.2.4.4 Analysis of scanning tactics

To get an idea about the most touched and the least touched areas on the screen during learning and evaluation tasks, the touched-screen has been divided into 16 areas equal in size, as presented in figure 5.4 (areas r00...r03, r10...r13, r20...r23, r30...r33), and the average of touches in each area has been calculated for all participants.

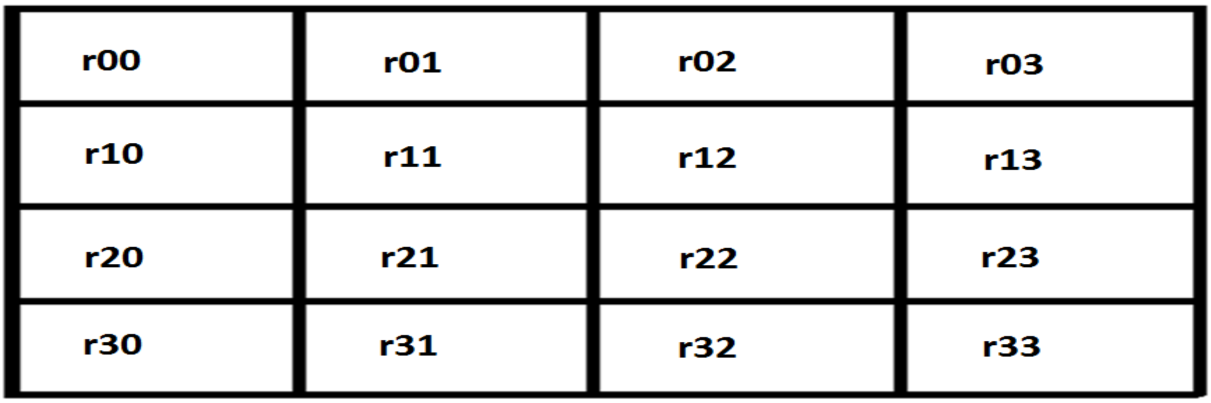


Figure 5.4 A division of 16 areas of the touched-screen.

After analyzing the touching points in each area, it was founded that the most touched areas are r12, r11, r22, r21, and the least touched areas are r30, r33, r32, r00 as described in figure 5.5. This piece of information might be useful in designing the graphical vibro-tactile language by concentrating the important information in the most touched areas.

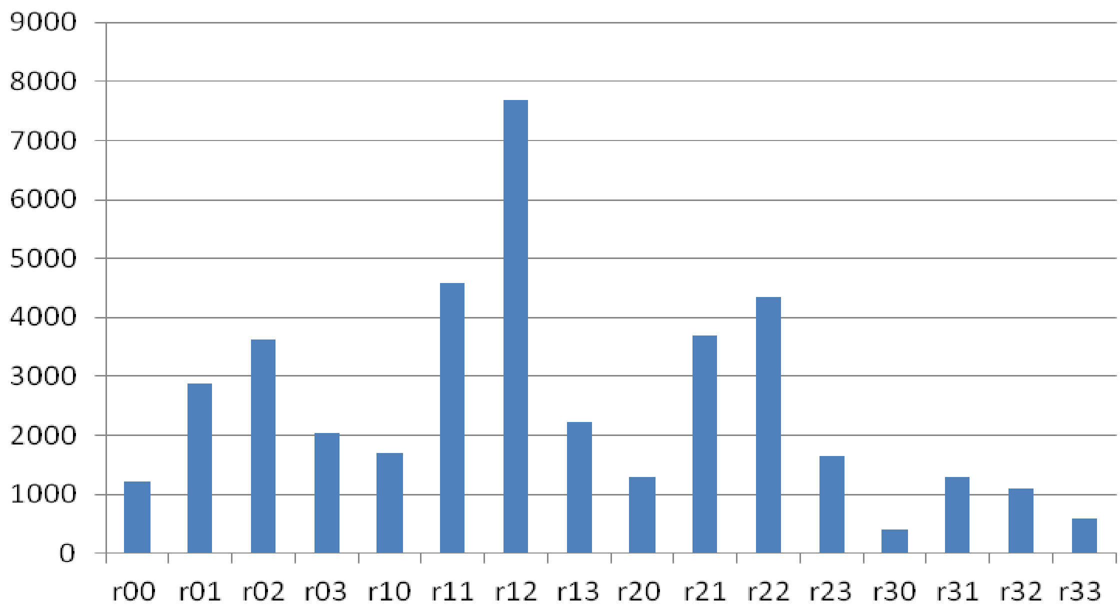


Figure 5.5 Sum of touched points in each area for all blind participants.

During analysis the results, it was noticeable that there are distinctive differences of pressure values between all the participants (pressure value depends on the type and the version of the tablet). To analyze the pressure values, the max, the min, and the average pressure values have been calculated. The max pressure value between all users was 3.19, and the average was 1.73. The touched points in each evaluation task and for each participant have been presented on the tablet. Points with pressure values equal to the max value have been drawn in red color. Points with pressure values less than the max and greater than the average have been drawn in blue color. Points with pressure values less than the average have been drawn in green color.

After analyzing all the images drawn for all users for all evaluation tasks, it was observed that the majority of red points (max pressure) are in images for which users gave right answers. This notice is useful in designing the desired graphical vibro-tactile language. The increasing of pressure indicates that the user touches graphical elements interesting for him/her, and the decreasing indicates that the user touches graphical elements non-interesting for him/her.

5.2.5 Conclusion of first experiment: pre-tests for examining the performance in recognizing shapes through vibro-tactile feedbacks

Results of the first experiment show that it is possible to recognize graphical shapes represented on touch-screen mobile devices via vibro-tactile feedbacks. Representing graphical shapes as a series of gray scales transactions and mapping these different shades of gray scales into tactile vibrations might be an effective non-visual way for fast shape recognition.

The obtained results during this experiment validate a basic hypothesis that visually impaired persons can explore graphical geometrical shapes presented on touch-screen mobile devices, and they can perceive their varieties in size, form, spatial relations, and semantic contents by using vibro-tactile feedbacks.

To summarize the results obtained in this experiment with sighted and blind persons:

- the less the shape has gradient transitions, the more it is recognizable;
- a black background will be effective for a fast but approximate shape recognition [Maurel et al., 2012];
- a gradient background from dark gray to light gray will be useful for a precise search but slower [Maurel et al., 2012];
- too many transitions to access an element leads to a degradation of the effectiveness of the recognition phase in terms of time and quality of response [Maurel et al., 2012];
- the most touched areas while navigating the presenting shapes are the centric areas (cf. areas r12, r11, r22, r21 in figure 5.5);
- the more the user increases the pressure on the touched surface, the more he/she is interested in the touched graphical element.

Depending on the previous conducted experiments, the following basic model of a graphical vibro-tactile language could be proposed:

$$GVTL = \{G, D, F, V, A, T\}$$

- GVTL is the graphical vibro-tactile language,
- G is a set of graphical symbols,
- D is a set of distances between the graphical symbols,
- F is a set of frequencies: $F=\{f: f \in [0 \text{ Hz}, 1992 \text{ Hz}]\}$, 1992 Hz is the maximum frequency value available by TactiNET device,
- A is a set of amplitudes: $A=\{a: a \in [0,255]\}$,
- T is a set of textures for the graphical symbols, and

- V is set of vibrations. Each vibration is represented by two values: f (frequency) and a (amplitude). The V set could be represented as following:

  $V=\{(f,a) : f \in F, a \in A$, F is a set of frequencies, A is a set of amplitudes$\}$

  If one of the values a or f is equal to 0, The system does not generate any vibration.

The values of sets D, F, A, and T will be defined in more details in next experiments. The group G represents a set of graphical symbols. Basically, this group was represented in the previous conducted experiment by geometrical shapes such squares, rectangles, and other polygonal shapes (cf. figures 5.1 and 5.2). This group can include other types of symbols rather than polygonal shapes such circles or others graphical symbols.

T is a set of textures that are dedicated for the graphical symbols. Each graphical symbol has a texture. The textures could be of different types such a plain black background texture or a gradient background texture (cf. figures 5.1 and 5.2). When the user touches a point that does not belong to any of the graphical symbols, the values of frequency and amplitude are equal to 0, and no vibration will be generated. When the user touches a point inside one of the graphical symbols, the values of frequency and amplitude will be related by the dedicated texture of that point, and a suitable vibration will be generated.

This simple GVTL will be developed and extended depending on the results of next experiments. Next two experiments aim to determine in more details the most perceptible and discriminated ranges of frequencies (set F) and amplitudes (set A).

5.3 Second experiment: selecting most perceptible and discriminated ranges of frequencies

5.3.1 Objectives of the experiment

The second experiment aims to select a range of frequencies most perceptible by sighted and visually impaired persons. These ranges of frequencies will be used in generating vibro-tactile feedbacks that represent contrasts of visual elements in web pages. Another objective of this experiment is to compare the differences between sighted and blind participants in perceiving different ranges of frequencies, in addition to study the effects of some types of amplitude variabilities on perceiving the vibration feedbacks.

5.3.2 Participants in the experiment

A group of sighted and blind persons have participated in this experiment. The participants are different in ages. 63 persons have participated in this experiment. 38 of the participants are children, and 25 of them are adult.

The 38 children are sighted. They are divided into two groups depending on their ages. The average of ages for the first group is 7.1 years, with a standard deviation 0.81 years. The average of ages for the second group is 9.42 years, with a standard deviation 0.61 years. All the children are students of schools in Caen city in France, and they participated in this experiment after obtaining a written approval of their parents.

The 25 adult participants are divided in two groups. The first group consists of 20 sighted persons. The average of their ages is 29.8 years, with a standard deviation 11.45 years. The second group consists of 5 blind persons. The average of their ages is 57 years, with a standard deviation 12.04 years.

The experiments with the 5 blind participants have been organized by the Cécitix association [Cécitix, 2016]. All of the 5 blind participants know and use the Braille coding. They are different in the date of their vision loss. Some of them have a congenital vision loss (since birth), and others have adventitious vision loss (after birth). All these experiments have been conducted in collaboration with PALM laboratory [PALM-Unicaen, 2016] [Bouget, 2015] with a strong interaction with me to build and to program the experimental device.

5.3.3 Protocol of the experiment

Each experiment (either for sighted or blind persons) consists in a series of tests to navigate two equal-sized parts on the touched screen, and to decide if the vibration feedbacks generated when touching the first part are identical or not to those vibration feedbacks generated when touching the second part.

To run the experiments, two tablets of type Samsung GALAXY Tab 2 (10.1 inch) [Samsung_galaxy_tab_2, 2016], and Samsung Galaxy Tab S (10.5 inch) have been used. The first tablet is dedicated to be used by the participant, and connected with the second prototype device of TactiNET (detailed in section 4.4 of the fourth chapter). The second tablet is dedicated to the experimenter. The two tablets are connected by a Bluetooth connection.

Two Android interfaces have been designed to be installed on the two tablets, and to be used by the experimenter and the participants. The first interface, dedicated to the experimenter, allows controlling the experiment by connecting the two interfaces and transferring information between them, and by selecting the frequency and the amplitude values for each stimulus. In this experiment, all the amplitude values are fixed initially to 255 (the maximum amplitude value), and only the frequency values are changed from one test to another. Figure 5.6 presents the experimenter interface. More details about some parameters in this interface are presented in next sections.

Figure 5.6 The experimenter interface for the second experiment.

The second interface dedicated to the participant divides the tablet into two parts. The first part (left part of the screen) is dedicated to a reference frequency. The second part (right part of the screen) is dedicated to a target frequency to be compared with the reference frequency. When the participant touches the first part of the screen, the actuator generates vibration feedbacks with a frequency value equals to the reference frequency and with amplitude value equals initially to 255. When the participant touches the second part, the actuator generates vibration feedbacks with a frequency value to be compared with the reference frequency and with amplitude value equals initially to 255. The participant mission is to navigate the two parts of the touched screen, and to decide if the generated vibrations are equal or not. Figure 5.7 presents an example of the participant interface.

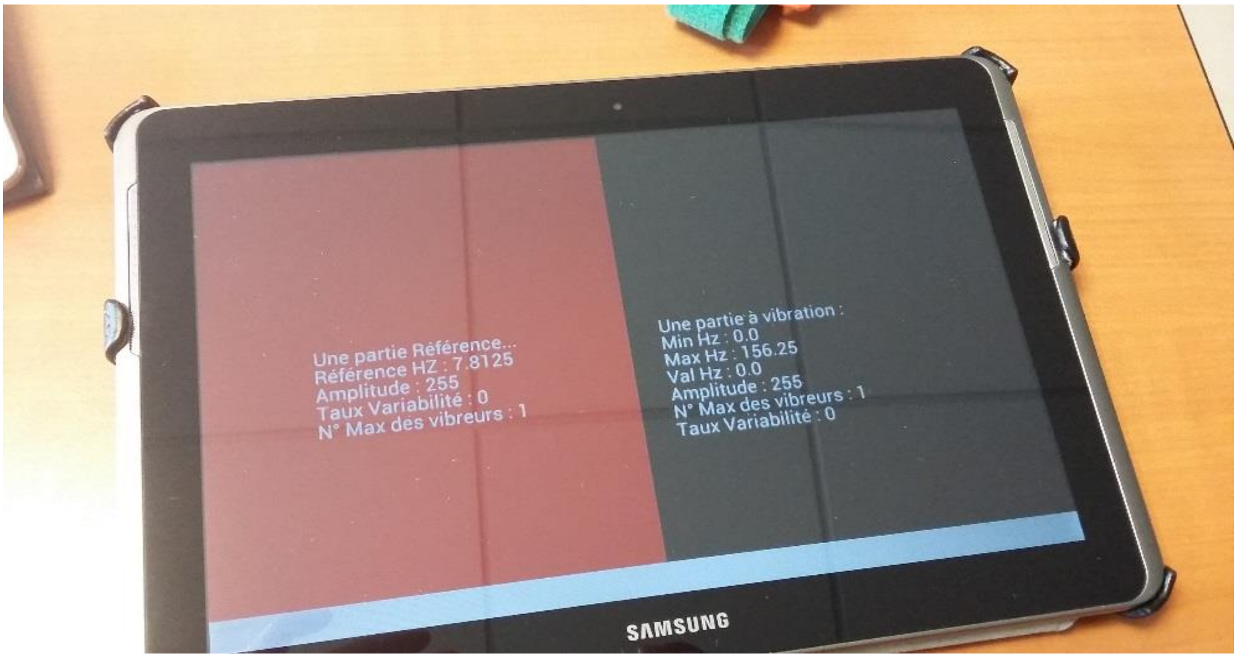


Figure 5.7 An example of the participant interface.

All the tests in this experiment have been conducted with only one actuator. The participant navigates the tablet with one of his hands' fingers (left or right), and puts a finger of the another hand on the actuator to perceive the vibrations. Only one question is proposed in every comparison "are *the vibration feedbacks generated when navigating the left part equal to that generated when navigating the right part*".

In this experiment, there is not any time limitation on the participant to support an answer for each question. During the experiment, it was noticeable that users always start navigating the screen from the left part to the right part.

To select which ranges of frequencies are the most perceptible by sighted and blind participants, five frequencies have been chosen to be tested as reference frequencies: 101.5625Hz; 203.125Hz; 304.6875Hz; 406.25Hz; and 500Hz. Each value of these five reference frequencies have been tested with two conditions of amplitude variability V0 and V5. Variability V0 means that the amplitude value is always 255 for all the vibration feedbacks generated when the participant navigates any part of the tablet screen. Variability V5 means that the amplitude value is between 255 and 250 (255-5). When the variability V5 is activated, a random integer value between 0 and 5 will be generated for each touch on any part of the tablet screen. This random integer value will be subtracted from the maximum amplitude value 255. The objective of adding these two types of variability is evaluating the framework sensitivity in public or noisy environments. A simple changing in the amplitude value could be a simulation of generating some noisy factors. So, the variability V0 simulates using the framework in non-noisy environments, and the variability V5 simulates using the framework in noisy environments.

After selecting the reference frequency values, the values of non-reference frequencies to be compared with the reference values should be determined. Each reference frequency value is compared with values of 10 series (5 ascendants and 5 descendants) of non-reference frequencies. Each series consists of 13 successive values. The difference between every two successive values in the same series is 7.8125Hz. The reference frequency value is the center value of each series. The experimenter starts always with a ascendant series. Table 5.8 views the series values for each reference value.

Table 5.8 Reference frequencies, and series of non-reference frequencies (in Hz).

Ref1=101.5625	Ref2=203.125	Ref3=304.6875	Ref4=406.25	Ref5=500
54.6875	156.25	257.8125	359.375	453.125
62.5	164.0625	265.625	367.1875	460.9375
70.3125	171.875	273.4375	375	468.75
78.125	179.6875	281.25	382.8125	476.5625
85.9375	187.5	289.0625	390.625	484.375
93.75	195.3125	296.875	398.4375	492.1875
101.5625	203.125	304.6875	406.25	500
109.375	210.9375	312.5	414.0625	507.8125
117.1875	218.75	320.3125	421.875	515.625
125	226.5625	328.125	429.6875	523.4375
132.8125	234.375	335.9375	437.5	531.25
140.625	242.1875	343.75	445.3125	539.0625
148.4375	250	351.5625	453.125	546,875

For each reference frequency, the experimenter starts the comparisons by the first value of an ascendant series. For each comparison between a reference frequency and a non-reference frequency, the experimenter asks the participant about the equality of generated vibrations. The answer is always either yes or no. When the participant supports two equal successive answers that are different from the first answer in the series, the experimenter stops the comparisons in the current series, and starts another comparison in the next series of the same type (ascendant or descendant).

For the adult participants, all the reference frequencies and the amplitude variabilities have been evaluated. The maximum number of comparisons for each adult participant is F5 x V2 x S10 x V13 =1300, where F5 refers to the five reference frequencies, V2 refers to the two types of variabilities V0 and V5, S10 refers to 10 series (5 ascendants and 5 descendants), V13 refers to the 13 values for each series. The average time to run the experiment with each adult participant is 2.5 hours. For the children, only three of reference frequencies have been evaluated (101.5625 Hz, 203.125 Hz, 400.25 Hz), due to the inability of conducting this experiment with the children for a long time. To select the most perceptible ranges of frequencies, the perceptual threshold and the differential perceptual threshold for each reference frequency have been calculated. The perceptual threshold PT_{ref} for each reference frequency REF is the average of the perceptual thresholds of its descendant series (5 descendant series) and the perceptual thresholds of its ascendant series (5 ascendant series).

$$PT_{ref} = (PT_{descendant\text{-}series} + PT_{ascendant\text{-}series})/2$$

The perceptual threshold of descendant (or ascendant) series $PT_{descendant\text{-}series}$ is the mean value of the perceptual thresholds of its 5 series (S_1, S_2, S_3, S_4 and S_5).

$$PT_{descendant\text{-}series} = (PT_{S1} + PT_{S2} + PT_{S3} + PT_{S4} + PT_{S5})/5$$

The perceptual threshold of a series is the mean value of its successive values that have been compared with the reference frequency. Table 5.9 represents an example of calculating the perceptual thresholds of 5 descendant series for the reference value 101.5625. In table 5.9, “yes” and “no” refer to the user answers about the equality between the reference value and a non-reference value.

Table 5.9 An example of calculating the perceptual thresholds of 5 descendant series.

Ref1=101.5625									
D1	User	D2	User	D3	User	D4	User	D5	User
54.6875	yes	54.6875		54.6875		54.6875		54.6875	
62.5	yes	62.5		62.5		62.5		62.5	
70.3125	yes	70.3125	yes	70.3125		70.3125		70.3125	
78.125	no	78.125	yes	78.125		78.125		78.125	
85.9375	no	85.9375	yes	85.9375	no	85.9375		85.9375	
93.75		93.75	no	93.75	yes	93.75		93.75	
101.5625		101.5625	no	101.5625	no	101.5625	no	101.5625	
109.375		109.375		109.375	yes	109.375	no	109.375	
117.1875		117.1875		117.1875	yes	117.1875	no	117.1875	no
125		125		125		125	yes	125	yes
132.8125		132.8125		132.8125		132.8125	yes	132.8125	no
140.625		140.625		140.625		140.625		140.625	yes
148.4375		148.4375		148.4375		148.4375		148.4375	no
PT Series	70.31		85.93		101.6		117.188		132.81
PT descendant Series	101.5625								

After measuring the perceptual threshold for each reference frequency for each participant. The perceptual threshold for each reference frequency for each group is calculated. The perceptual threshold for certain reference frequency (REF) for a group (G) is the average of perceptual thresholds of that reference frequency for all the group members (N members).

$$PT_{G,ref}=(PT_{user1,ref} + PT_{user2,ref} + PT_{user3,ref} +\ldots+ PT_{userN,ref})/N$$

The differential perceptual threshold DT for each reference frequency REF is calculated by subtracting the perceptual threshold value from the value of the reference frequency:

$$Dt_{ref}=| PT_{ref} - \text{reference frequency}|$$

The result is represented as an absolute value. For example, for the reference frequency 101.5625Hz, if the perceptual threshold is 99.01Hz, the differential perceptual threshold will be |101.5625 - 99.01|=2.5525Hz. The differential perceptual threshold is that it indicates how the perceptual threshold is far or close of the reference frequency value.

There were two main hypotheses when calculating the perceptual thresholds for all the groups. The first one is “null hypothesis” [Moore et al., 2003]. This hypothesis H_0 means that there is no significant difference among the mean values of perceptual thresholds for all the groups.

$$H_0: m_1 = m_2 = m_3 \ldots = m_k$$

Where m_i is mean values of perceptual thresholds for the group i.

The second hypothesis H_1 is that there is a significant difference between the mean values of perceptual thresholds for all the groups.

$$H_1: \text{averages are not equal}$$

5.3.4 Results of the experiment

The differential perceptual thresholds for each reference frequency have been calculated under two conditions: variability V0, and variability V5. These values have been calculated for 5 adult blind participants (Average = 57 years, Standard deviation (SD) = 12.04 years) and for 5 adult sighted participants (Average = 46 years, SD = 3.24 years). Table 5.10 presents the average values of differential perceptual thresholds for each reference frequency under variabilities V0 and V5. Figure 5.8 presents the mean and standard deviation values of differential perceptual thresholds for adult sighted and blind participants with two conditions of variability V0 and V5.

Table 5.10 Average values of differential perceptual thresholds of sighted and blind persons for each reference frequency under variabilities V0 and V5.

Reference Frequency (Hz)	V0	V5
101.5625 Hz	16.27122 Hz	12.48638 Hz
203.125 Hz	12.45846 Hz	12.97066 Hz
304.6875 Hz	5.05669 Hz	7.48014 Hz
400.25 Hz	10.54997 Hz	9.55368 Hz
500 Hz	13.54778 Hz	16.60168 Hz

In table 5.10, it is noticeable that the reference frequency 304.6875Hz has the smallest differential perceptual thresholds either with the variability V0 or with the variability V5. This result is confirmed by an ANOVA analysis [Moore et al., 2003] aims to estimate the effect of changing the reference frequency on the differential perceptual thresholds. The analysis has been calculated taking into account two types of variabilities, and the visual status of the participants (sighted or blind). The analysis indicated an effect for changing the reference frequency: $F(4,28) = 3.58$, $p = 0.017$, $\alpha= 0.81$. An analysis post-hoc with the test of Bonferroni [Moore et al., 2003] has indicated that the differential perceptual threshold for the reference value 304.6875 Hz is the least important comparing with other differential perceptual thresholds. This result means that the range of frequencies close to value 304.6875 Hz is more perceptible and discriminated than ranges of frequencies close to other tested reference frequencies.

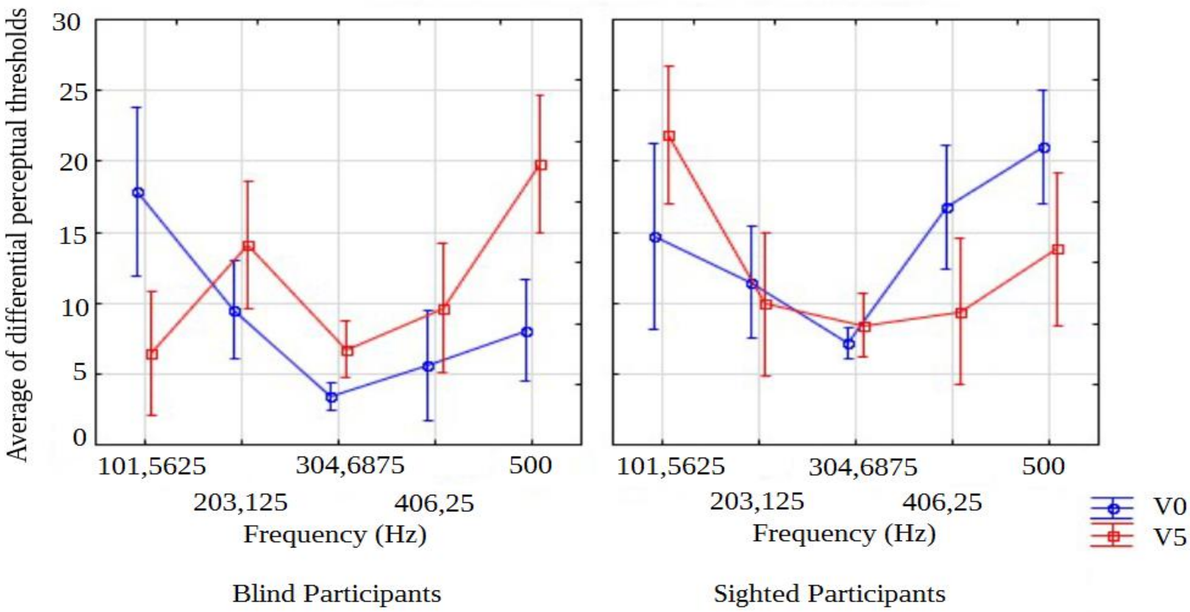


Figure 5.8 Mean and standard deviation values of differential perceptual thresholds for adult sighted and blind participants with two conditions of variabilities V0 and V5.

An ANOVA analysis has been conducted to estimate the effect of the amplitude variability (V0 or V5) on the differential perceptual thresholds. The analysis did not indicate any effect of the variability: $F(1,8) = 0.052$, $p = 0.83$, $\alpha=0.05$. This means that the simple amplitude variabilities do not affect on the performance of the participants.

Another ANOVA analysis has been conducted to estimate the effect of the visual status of the participant (sighted or blind) on the differential perceptual thresholds. The analysis did not indicate any effect of the visual status: $F(1,8) = 0.451$, $p = 0.07$, $\alpha=0.05$. This means that the performance of sighted participants is nearly equal to the performance of blind participants.

Many tests have been conducted with the groups of the children participating in this experiment. Some of the reference frequencies have been evaluated (101.5625 Hz, 203.125 Hz, 400.25 Hz), due to the inability to conduct the experiment with the children for a long time. The children have been divided into two groups depending on their ages. The average of ages for the first group is 7.1 years (group G1). The average of ages for the second group is 9.42 years (group G2).

An ANOVA analysis has been conducted to estimate the effect of the children age (group G1 and group G2) on the differential perceptual thresholds. The analysis did not indicate a significant effect of the age: $F(1,36) = 0.28$, $p = 0.59$, $\alpha=0.081$. The average of the differential perceptual thresholds for the first group was 17.06 Hz, while it was 18.02 Hz for the second group.

Another ANOVA analysis has been conducted to estimate the effect of the amplitude variabilities (V0 and V5) on the differential perceptual thresholds. The analysis did not indicate a significant effect of the variability: $F(1,36) = 2.02$, $p = 0.17$, $\alpha=0.028$. This means that the simple amplitude variabilities do not affect on the performance of the children participants.

An ANOVA analysis indicated an effect of the type of the series (descendant or ascendant) on the differential perceptual thresholds: F(1,36)=6.23, p=0.018, α=0.68. The average of differential perceptual thresholds in series of type descendant (=20.10Hz) is larger than the average of differential perceptual thresholds in series of type ascendant (=14.98). Another ANOVA analysis indicated an effect of the children age (group G1 and group G2) and the type of the series (descendant or ascendant) on the differential perceptual thresholds: F(1,36)=10.16, p=0.0032, α=0.87. An analysis post-hoc with the test of Bonferroni has indicated that:

- for the group G1 (average of ages is 7.1 years): the average of differential perceptual thresholds in series of type descendant (average=22.95 Hz) is larger than the average of differential perceptual thresholds in series of type ascendant (average=11.18 Hz).
- for the group G2 (average of ages is 9.4 years): the average of differential perceptual thresholds in series of type ascendant (average=18.78 Hz) has not a significant difference comparing with the average of differential perceptual thresholds in series of type descendant (average=17.26 Hz).

This result means that young children (represented by G1) are more sensible for changes in series directions, and they present better results in series of type ascendant more than series of type descendant. Figure 5.9 presents the average and standard deviation values of differential perceptual thresholds for the groups G1 and G2, and for the series ascendant and descendant.

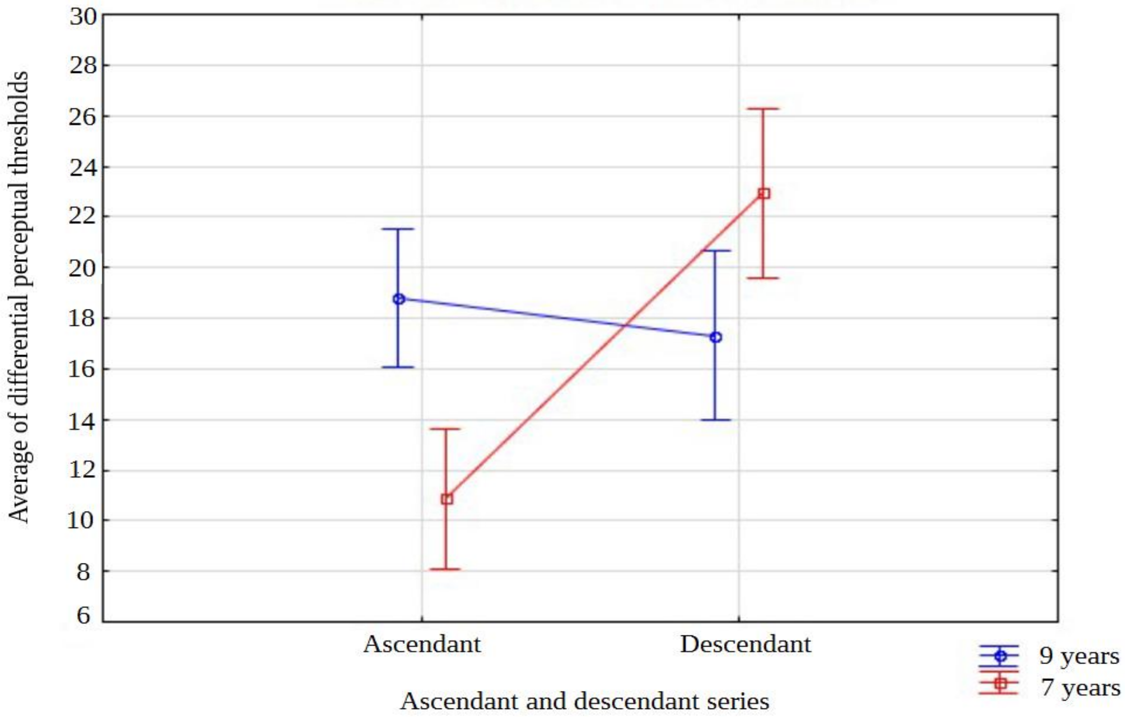


Figure 5.9 The mean and standard deviation values of differential perceptual thresholds for the groups G1 (7 years) and G2 (9 years), and for the series ascendant and descendant.

5.3.5 Conclusion of the second experiment: selecting most perceptible and discriminated ranges of frequencies

This experiment aimed to select the most perceptible ranges of reference frequencies with two types of amplitude variabilities. The results mentioned that there is no significant difference in applying the two types of variabilities. The results indicated that it is possible for adult participants to detect a very simple difference between frequencies close to the frequency 304.6875 Hz. This ability of discrimination is not identical for differences close to other frequencies such 500 Hz. This result is close to another study indicated that navigating the digital devices is more sensible to vibrations with frequencies starting from 200-250 Hz [Moore et al., 2003]. The results indicated that there is not a significant difference between the sighted and blind participants in perceiving the evaluated referential frequencies. These results will be used in next experiments to decrease the number of achieved tests. No types of variabilities will be used in next experiments, and the main used frequency will be 304.6875 Hz [Safi et al., 2016].

To summarize the results obtained in this experiment with sighted and blind persons:

- the reference frequency 304.6875Hz has the smallest differential perceptual thresholds either with the variability V0 or with the variability V5,
- the range of frequencies close to value 304.6875 Hz is more perceptible and discriminated than ranges of frequencies close to other tested reference frequencies,
- changing amplitude values with simple variabilities do not affect on the performance of the participants,
- the performance of sighted and blind participants is nearly equal in discriminating ranges of frequencies,
- there is no significant effect of the age in discriminating ranges of frequencies,
- young children are more sensible for changes in series directions, and they present better results in series of type ascendant more than series of type descendant.

Depending on this conducted experiment, the basic model GVTL = {G, D, F, V, A, T} could be extended in what concerns the set of frequencies F. F has been defined as a set of frequencies: F = {f: f∈[0 Hz, 1992 Hz]}, where 1992 Hz is the maximum frequency value available by TactiNET device. Depending on the conducted experiment, the set F could be redefined as following F = {f: f∈[50 Hz, 550 Hz]}. Five ranges (R1, R2, R3, R4, R5) could be distinguished in this set:

- R1=[50 Hz, 150 Hz[, in case of choosing two frequencies from this range to represent two objects by TactiNET, the minimum difference between the two chosen values should be greater than 14.38 Hz. This difference value has been calculated depending on the data presented in table 5.10.
- R2=[150 Hz, 250 Hz[, the minimum difference between two chosen values from this range should be greater than 12.71 Hz.
- R3=[250 Hz, 350 Hz[, the minimum difference between two chosen values from this range should be greater than 6.27 Hz.
- R4=[350 Hz, 450 Hz[, the minimum difference between two chosen values from this range should be greater than 10.05 Hz.
- R5=[450 Hz, 550 Hz[, the minimum difference between two chosen values from this range should be greater than 15.07 Hz.

These values of frequencies should be correlated with values of amplitude in order to generate suitable vibration signals. The next experiment evaluates the thresholds of discriminating a set of amplitude values.

5.4 Third experiment: selecting most perceptible and discriminated ranges of amplitudes

5.4.1 Objectives of the experiment

The third experiment aims to evaluate the thresholds of discriminating a set of amplitudes (intensities) by sighted and visually impaired persons. These values of amplitudes will be used (in addition to values of frequencies) to generate vibro-tactile feedbacks that represent contrasts of visual elements in web pages. This experiment compares also the performance of sighted and blind participants of different ages.

5.4.2 Participants in the experiment

20 persons have participated in this experiment. 15 of the participants are sighted, and 5 of them are blind. The average of ages for the first group (sighted participants) is 24.5 years, with a standard deviation 4.3 years. The average of ages for the second group (blind participants) is 57.5 years, with a standard deviation 11.65 years. The experiments with blind participants have been organized by the association Cécitix [Cécitix, 2016]. The 5 blind participants are different in date of their vision loss. Two of them have a congenital vision loss (since birth), and three others have adventitious vision loss (after birth). All the sighted participants are students in university of Caen-Normandie in France. All these experiments have been conducted in collaboration with PALM laboratory [PALM-Unicaen, 2016] [Guilbert, 2015] with a strong interaction with me to build and to program the experimental device.

5.4.3 Protocol of the experiment

Protocol of this experiment is very similar to the protocol discussed in the previous experiment (section 6.3.3). The same tablets and TactiNET device as in the previous experiment were used in this experiment. The experiment consists in a series of tests to navigate two equal-sized parts on the touched screen, and to decide if the vibration feedbacks generated when touching the first part are identical or not to those vibration feedbacks generated when touching the second part.

Two Android interfaces have been designed to be installed on the two used tablets, and to be used by the experimenter and the participants. The first interface dedicated to the experimenter allows controlling the experiment by connecting the two interfaces and transferring information between them, and by selecting the frequency and the amplitude values for each stimulus. In this experiment, all the frequency values are fixed to 304.6875 Hz (depending on results of the previous experiment), and only the amplitude values are changed from one test to another. The second interface dedicated to the participant divides the tablet into two parts. The first part (left part of the screen) is dedicated to reference amplitude. The second part (right part of the screen) is dedicated to target amplitude to be compared with the reference amplitude. When the participant touches the first part of the screen, the actuator generates vibration feedbacks with a frequency value equals 304.6875 Hz, and with amplitude value equals to the reference amplitude. When the participant touches the second part, the actuator will generate vibration feedbacks with a frequency value equals 304.6875 Hz, and with an amplitude value to be compared with the reference amplitude value.

Similar to the previous experiment, all the tests in this experiment have been executed with only one actuator. The participant navigates the tablet by using the index of his/her preferred hand (left or right). The actuator to perceive the vibrations is placed on the non-preferred hand. Only one question is proposed in every test: "are the vibration feedbacks generated when navigating the left part equal to that generated when navigating the right part?". There is no time limitation for the participant to answer each question.

Three amplitudes have been chosen to be tested as reference amplitudes: 55; 155; and 255. To select the threshold of discrimination for each reference amplitude, the method "staircase" or "up-and-down method" [Treutwein, 1995] has been used with two series of values (ascendant and descendant). This method usually begins with a high intensity stimulus. The intensity is then reduced until the experimenter decides to stop the current series, at this point the staircase 'reverses', the intensity is increased, and the comparisons continue until the experimenter decides to stop the series again, and to decrease the intensity, triggering another reversal. The average of these 'reversals' is considered as a threshold of discrimination. Each reference amplitude value is compared with values of 18 series (9 ascendants and 9 descendants) of non-reference amplitudes. Each series consists of many successive values. The difference between every two successive values in the same series is different from one series to another. The interval step or the difference between every two successive values in the first two series (1D and 2A) is 30. The symbols A and D refer to ascendant and descendant series respectively. The interval step in the second two series (3A and 4D) is 15. The interval step in the third two series (5D and 6A) is 7. The interval step in the fourth two series (7A and 8D) is 3. The interval step in the last ten series (9D, 10A, 11A, 12D, 13D, 14A, 15A, 16D, 17D, 18A) is 1. Table 5.11 presents the series, and the differences between their successive values.

Table 5.11 Ascendant and descendant series, and the differences between their successive values.

1D	2A	3A	4D	5D	6A	7A	8D	9D	10A	11A	12D	13D	14A	15A	16D	17D	18A
30	30	15	15	7	7	3	3	1	1	1	1	1	1	1	1	1	1

The experimenter starts with the first descendant series 1D. When the participant supports two equal successive answers that are different from the first answer in the series, the experimenter stops the comparisons in the current series. At this point, the experimenter reverses the direction and starts other comparisons in a next series of a different type (3A) and with a reduced intensity value. The experimenter starts the series 3A from the same last tested value in the series 1D, or from a value very close to it. The experimenter repeats this scenario for all the other series. Table 5.12 presents an example of applying the method on series 1D, 2A, 3A, and 4D of the reference amplitude 55. Table 5.13 presents an example of applying the method on series 5D, 6A, 7A, and 8D of the reference amplitude 55.

Table 5.12 Applying Staircase method on series 1D, 2A, 3A, and 4D of the reference amplitude 55.

Series	1D	1D User	2A	2A User	3A	3A User	4D	4D User
Interval step	30		30		15		15	
Values	255		255		250		250	
	235	No	235		235		235	
	205	No	205		220		220	
	175	No	175		205		205	
	145	No	145		190		190	
	115	Yes	115		175		175	
	85	Yes	85		160	No	160	
	55		55	Yes	145	No	145	
	25		25	Yes	130	Yes	130	
	0		0	No	115	Yes	115	
					100	Yes	100	
					85	Yes	85	
					70		70	
					55		55	Yes
					40		40	No
					25		25	No
					10		10	
					0		0	

Table 5.13 Applying Staircase method on series 5D, 6A, 7A, and 8D of the reference amplitude 55.

Series	5D	5D User	6A	6A User	7A	7A User	8D	8D User
Interval step	7		7		3		3	
Values	216		216		148		148	
	209		209		145		145	
	202		202		142		142	
	195		195		139		139	
	188		188		136		136	
	181		181		133		133	
	174		174		130		130	
	167		167		127	No	127	
	160	No	160		124	No	124	
	153	Yes	153		121	Yes	121	
	146	No	146		118	Yes	118	
	139	Yes	139		115		115	
	132	No	132		112		112	
	125	Yes	125		109		109	
	118	Yes	118		106		106	
	111		111		103		103	
	104		104		100		100	
	97		97		97		97	
	90		90		94		94	
	83		83		91		91	
	76		76		88		88	
	69		69		85		85	
	62		62		82		82	
	55		55		79		79	
	48		48		76		76	
	41		41	Yes	73		73	
	34		34	Yes	70		70	
	27		27	No	67		67	
	20		20	No	64		64	
	13		13		61		61	
	6		6		58		58	
	0		0		55		55	
					52		52	
					49		49	
					46		46	
					43		43	
					40		40	Yes
					37		37	Yes
					34		34	Yes
					31		31	No
					28		28	No
					25		25	

After finishing testing all the series for each reference amplitude. A representative value is calculated for each series of the last ten series (9D, 10A, 11A, 12D, 13D, 14A, 15A, 16D, 17D, 18A). This representative value is determined by calculating the average of the two values that make the inversion in the participant answer. Table 5.14 presents examples of calculating the representative values for series 9D, 10A, 11A, 12D of the reference amplitude 55.

Table 5.14 Representative values for series 9D, 10A, 11A, and 12D of the reference amplitude 55.

Series	9D	9D User	10A	10A User	11A	11A User	12D	12D User
Interval step	1		1		1		1	
Values	130		41		130		40	
	129		40		129		39	
	128		39		128		38	
	127	No	38		127	No	37	
	126	No	37		126	No	36	
	125	No	36		125	Yes	35	
	124	No	35		124	Yes	34	Yes
	123	Yes	34	Yes	123	Yes	33	Yes
	122	Yes	33	Yes	122	Yes	32	No
	121		32	No	121		31	NO
	120		31	Yes	120		30	
	119		30	No	119		29	
	118		29	No	118		28	
	117		28	No	117		27	
	116		27		116		26	
	115		26		115		25	
Representative Value	123,5		32,5		125,5		32,5	

The superior perceptual threshold and the inferior perceptual threshold for each reference amplitude have been calculated using the representative values in the last ten series. The superior perceptual threshold for a reference amplitude REF is calculated as the average of the representative values for the last 5 descendant series (9D, 12D, 13D, 16D, 17D). The inferior perceptual threshold for a reference amplitude REF is calculated as the mean value of the representative values for the last 5 ascendant series (10A, 11A, 14A, 15A, 18A).

Superior perceptual threshold (REF) = (rep(9D) + rep(12D) + rep(13D) + rep(16D) + rep(17D))/5.
Inferior perceptual threshold (REF) = (rep(10A) + rep(11A) + rep(14A) + rep(15A) + rep(18A))/5.
rep(x) means the representative value of the series x.

For the reference amplitude 255, the superior perceptual threshold has not been calculated because the maximum amplitude value in the designed device is 255.

The differential perceptual threshold (DPT) for each reference amplitude REF is the difference between the superior perceptual threshold (SPT) and the inferior perceptual threshold (IPT) divided by two.

$$DPT(REF) = (SPT(REF) - IPT(REF))/2$$

In what concerns the reference amplitude 255, the differential perceptual threshold DPT(255) has been calculated as following:

$$DPT(255) = 255 - IPT(255)$$

The differential perceptual threshold for a reference value REF is a numerical value represents the minimum difference between the REF and other amplitude values where the participant can discriminate them from the reference value.

The perceptual threshold PT has been calculated also for the reference amplitudes 55 and 155 as the average between the superior perceptual threshold (SPT) and the inferior perceptual threshold (IPT).

$$PT(REF) = (SPT(REF) + IPT(REF))/2$$

The perceptual threshold could be represented as a perceptual value between the superior and the inferior perceptual thresholds.

The average time of conducting the experiment with each user is two hours. Two hypothesis h_0 and h_1 were used. The first one is “null hypothesis” [Moore et al., 2003]. (there is no significant difference among the mean values of perceptual thresholds for all the groups).

$$H_0: m_1 = m_2 = m_3 ... = m_k$$

Where m_i is mean values of perceptual thresholds for the group i.

The second hypothesis is H_1:

$$H_1: \text{averages are not equal}$$

(there is a significant difference between averages of perceptual thresholds for all the groups).

5.4.4 Results of the experiment

5.4.4.1 Results of the experiment with sighted persons

The superior perceptual threshold (SPT) and the inferior perceptual threshold (IPT) values have been calculated for each reference amplitude and for each sighted participant. Table 5.15 represents these values for the amplitudes 255, 155, and 55.

Table 5.15 Superior perceptual thresholds and inferior perceptual thresholds (IPT) for sighted participants, and their standard deviation for the amplitudes 255, 155, and 55.

	Superior perceptual threshold (Descendant Series)		inferior perceptual thresholds (Ascendant Series)		differential perceptual threshold (DPT)
Reference Amplitude	Average	SD	Average	SD	
255	---	---	214.83	11.38	40.17
155	195.03	7.98	104.31	9.62	45.36
55	67.59	4.76	47.61	3.32	9.99

An ANOVA analysis has been conducted to estimate the effect of the type of the series (descendant or ascendant) and the reference amplitude (155 and 55) on the superior and inferior perceptual thresholds for sighted participants. The amplitude 255 has not been taken into account, due to the inability of calculating its superior perceptual threshold. The analysis indicated an effect for changing the reference amplitude: $F(1,14) = 3924.3$, $p < .0001$, $\alpha = 1$. The analysis indicated a significant effect of the amplitude 155 (Average = 149.67, SD = 46.94) more than the amplitude 55 (Average = 57.6, SD = 10.94). This result means that the superior and inferior perceptual thresholds of the reference amplitude 55 is less than superior and inferior perceptual thresholds of the reference amplitude 155. The analysis indicated also a significant effect of the type of the series (descendant or ascendant): $F(1, 14) = 476.44$, $p < .0001$, $\alpha = 1$. The average of perceptual thresholds for the descendant series (Average = 131.31, SD = 65.13) is larger than the average of perceptual thresholds for the ascendant series (Average=75.96, SD = 29.69).

An ANOVA analysis indicated an effect of the reference amplitude (255, 155 and 55) on the differential perceptual thresholds for the sighted participants: ($F(2, 28) = 139.99$, $p < .0001$, $\alpha = 1$). An analysis post-hoc with the test of Bonferroni [Moore et al., 2003] indicated that the average of differential perceptual thresholds of amplitude 55 (Average = 9.99, SD = 3.25) is significant less than the averages of differential perceptual thresholds of amplitude 155 (Average=45.36, SD = 7.33) and 255 (Average= 40.17, SD = 11.38).

5.4.4.2 Results of the experiment with blind persons

The superior perceptual threshold (SPT) and the inferior perceptual threshold (IPT) values have been calculated for each reference amplitude and for each blind participant. Table 5.16 represents these values for the amplitudes 255, 155, and 55.

Table 5.16 Superior perceptual thresholds and inferior perceptual threshold (IPT) values for blind participants, and their standard deviation for the amplitudes 255, 155, and 55.

	Superior perceptual threshold (Descendant Series)		inferior perceptual thresholds (Ascendant Series)		differential perceptual threshold (DPT)
Reference Amplitude	Average	SD	Average	SD	
255	---	---	206.13	8.96	48.87
155	190.34	16.91	90.34	15.08	50
55	71.22	9.45	44.96	4.49	13.13

An ANOVA analysis has been conducted to estimate the effect of the type of the series (descendant or ascendant) and the reference amplitude (155 and 55) on the superior and inferior perceptual thresholds for blind participants. The amplitude 255 has not been taken into account. The analysis indicated an effect for changing the reference amplitude: $F(1, 18) = 2950.5$, $p < 0.0001$, $\alpha = 1$. The analysis indicated a significant effect of the amplitude 155 (Average=147.34; SD=48.47) more than the amplitude 55 (Average=57.72; SD=12.02). This result means that the superior and inferior perceptual thresholds of the reference amplitude 55 is less than superior and inferior perceptual thresholds of the reference amplitude 155. The analysis indicated also a significant effect of the type of the series descendant or ascendant: $F(1, 18) = 351{,}69$, $p < 0.0001$, $\alpha = 1$. The average of perceptual thresholds for the descendant series (Average=131.18, SD=64.05) is larger than the mean value of perceptual thresholds for the ascendant series (Average=73.88, SD = 28.74). These results mean that "decreasing the amplitude from a reference value REF is more effective than increasing the amplitude to a reference value REF in order to make the participant feels a significant difference with a compared reference amplitude".

An ANOVA analysis indicated an effect of the vision status (sighted or blind) on the perceptual thresholds of all the participants: $F(1, 18) = 9.37$, $p < .01$, $\alpha = 0.82$. Following results have been obtained:

- for the reference amplitude 155: the average of perceptual thresholds of blind persons (Average=140.34; SD=54.83) is less than the average of perceptual thresholds (Average =149.67; SD = 46.94) of sighted participants.

- but, for the reference amplitude 55: there is no a significant difference between the average of perceptual thresholds of blind persons (Average=58.09, SD=15.48), and the average of perceptual thresholds of sighted persons (Average=57.6, SD=10.94). These results indicate that for some reference amplitudes (such as 155) there is a difference in the performance between the sighted and blind persons. But, for other reference amplitudes (such as 55), there is no difference in the performance between the sighted and blind persons.

An ANOVA analysis indicated an effect of the reference amplitude (255, 155 and 55) on the differential perceptual thresholds for the blind participants: ($F(2, 36)=146,38$, $p < .0001$, $\alpha = 1$). An analysis post-hoc with the test of Bonferroni indicated that the average of differential perceptual thresholds of amplitude 55 (Average = 10.78, SD = 4.37) is significantly less than the averages of differential perceptual thresholds of amplitude 155 (Average=46.52, SD=9.38) and 255 (Average= 42.34, SD = 11.28). These results are compatible to those for sighted persons and mean that "*for the sighted and blind persons, the minimal quantity of amplitude that should be increased or decreased to make the participant feels a significant difference with the reference amplitude is very simple for the amplitude 55 comparing with the amplitudes 155 and 255*".

5.4.5 Conclusion of the third experiment: selecting most perceptible and discriminated ranges of amplitudes

In this experiment, many amplitude values have been compared with three reference amplitudes 55, 155, and 255. Many comparisons have been conducted between the performance of sighted and blind persons. The results indicated that ranges of amplitudes close to amplitude 55 are more discriminated than ranges of amplitudes close to other tested amplitudes such as 155 and 255. The results indicated that there is no a significant difference between the sighted and blind participants in perceiving some evaluated referential amplitudes (such as 55), while there is a significant difference between the sighted and blind participants in perceiving some evaluated referential amplitudes (such as 155). This means that the difference in performance between sighted and blind persons is function to the amplitude value.

Depending on this conducted experiment, the basic model of a graphical vibro-tactile language GVTL = {G, D, F, V, A, T} could be extended in what concerns the set of amplitudes A. A has been defined as a set of amplitudes: $A = \{a: a \in [0, 255]\}$. Three ranges (R1, R2, R3) could be distinguished in this set:

- R1=[0, 100[, in case of choosing two values from this range to represent two objects by TactiNET, the minimum difference between the two chosen values should be greater than 11.56. This difference value has been calculated depending on the data presented in tables 5.15 and 5.16.
- R2=[100, 200[, the minimum difference between two chosen values from this range should be greater than 47.68.
- R3=[200, 255], the minimum difference between two chosen values from this range should be greater than 44.52.

5.5 Conclusion of Chapter 5

This chapter presented three experiments that have been conducted to select a series of values, and arguments that are fundamental for designing the graphical vibro-tactile language. These three experiments lead to:

- distinguish the effects of changing the texture on recognizing shapes through vibro-tactile feedbacks on touch-screen devices,
- select the most perceptible and discriminated ranges of frequencies through vibro-tactile feedbacks on touch-screen devices,
- select the most perceptible and discriminated ranges of amplitudes through vibro-tactile

feedbacks on touch-screen devices.

These results will be used in designed the last experience that aims to study the ability of discriminating the web pages structures via vibro-tactile feedbacks. This experience will be detailed in next part.

Part 3:

Recognizing the Structures of Web Pages Through Vibro- Tactile Feedbacks

Chapter 6:
Recognizing the Structures of Web Pages Through Vibro-Tactile Feedbacks

Résumé : L'évaluation de la performance des personnes voyantes et aveugles à reconnaitre des structures des pages Web est une étape fondamentale pour valider l'hypothèse proposée. L'hypothèse principale dans ce travail est que «les personnes malvoyantes peuvent explorer des formes géométriques graphiques présentées sur un appareil mobile avec un écran tactile, et elles peuvent percevoir leurs variétés en taille, en forme, en relations spatiales et en contenu sémantique en utilisant des retours vibro-tactiles".

Ce chapitre présente l'expérience principale qui a été menée avec des personnes aveugles et voyantes afin d'examiner leurs capacités à reconnaître les structures de pages Web grâce à des retours vibro-tactiles. Le chapitre commence par introduire les objectifs de l'expérience menée. Les formulaires conçus qui représentent des structures de pages Web sont présentés. Enfin, le protocole de l'expérience et les résultats sont présentés et discutés.

6.1 Introduction

Examining the performance of sighted and blind persons in recognizing the structures of web pages is a fundamental step to validate the proposed hypothesis. The main hypothesis in this work is that “visually impaired persons can explore graphical geometrical shapes presented on a touch-screen mobile device, and they can perceive their varieties in size, form, spatial relationships, and semantic contents using vibro-tactile feedbacks”.

This chapter presents the main experiment that has been conducted with blind and sighted persons to examine their abilities to recognize web pages structures through vibro-tactile feedbacks. The chapter begins by introducing the objectives of the conducted experiment. The designed forms that represent web pages structures are presented. Finally, the protocol of the experiment and the results are presented and discussed.

6.2 Objectives and designing the experiment

This experiment is based on converting semi-automatically the visual structures of web pages into vibrating pages. This conversion was achieved by representing the segments (clusters, zones, or blocks) of web pages as rectangular shapes, and representing the varieties in contrast of these segments’ contents by vibration signals. Representing the shapes as rectangles has been chosen depending on a series of experiments with sighted persons to understand how they segment web pages; and after running an empirical experiment with blind persons to examine their performance in recognizing rectangular shapes through vibro-tactile feedbacks. These two experiments are detailed in chapters 4 and 5. The ability of recognizing these rectangular shapes and distinguishing the variabilities of their dedicated vibration feedbacks indicates the ability of perceiving the web pages structures. Perceiving the web pages structures via vibro-tactile feedbacks could be considered as a new non-visual navigation solution for exploiting the two-dimension spatial information of web pages interfaces.

Three representative web pages (extracted from the constructed web corpus) have been chosen to be evaluated in this experiment. These three web pages represent the three categories in the constructed web corpus (touristic, e-commerce, and news). Extraction these representatives was described in section 4.5 in chapter 4. The agglomerative graph-based clustering algorithm suggested in chapter 4 has been applied on each representative page. The input of this algorithm is a web page. Its output is a graph of N segments (clusters), where each cluster contains similar (close) HTML elements. This agglomerative graph-based clustering method is a algorithm because the experimenter should select the value N that represents the desired number of clusters. In this experiment, the chosen number N equals 5. This option has been chosen depending on the theory of the magic number seven plus or minus two [Miller, 1956] that has been proposed for the first time in 1956, and it is known as Miller's Law [Miller, 1956]. This theory proposes that there is a limit on the human mental capacity to process information with reliable accuracy and with validity when interacting simultaneously many elements. This means that there is a limit in terms of the amount of information the person can receive, process, and remember. The theory proposes that the average number of objects that persons can hold in working memory (short-term memory – primary memory - active memory) is 7±2. In this experiment, to guarantee that the number of chosen clusters does not affect on the performance of the participants, the number 5 (7-2) has been chosen as a desired number of clusters [Miller, 1956].

Figures 6.1 and 6.2 view respectively the representative web page of the touristic category and its segmentation result. Figures 6.3 and 6.4 view respectively the representative web page of the e-commerce category and its segmentation result. Figures 6.5 and 6.6 view respectively the representative web page of the news category and its segmentation result. These results have been drawn on a tablet Samsung GALAXY Tab 2 [Samsung_galaxy_tab_2, 2016].

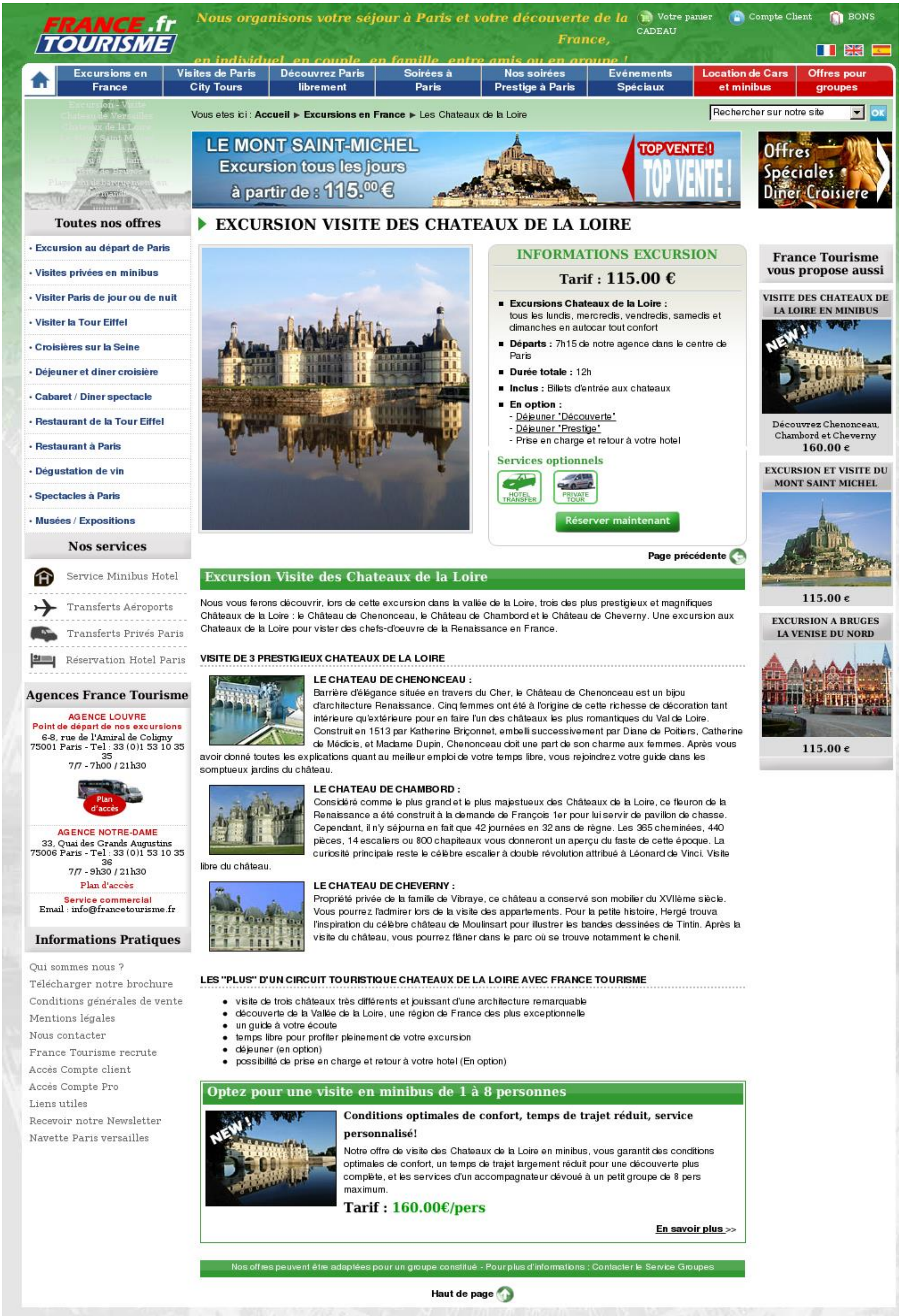


Figure 6.1 The homepage of site www.francetourisme.fr, a representative of the touristic category.

Figure 6.2 Segmenting the web page representative of the touristic category.

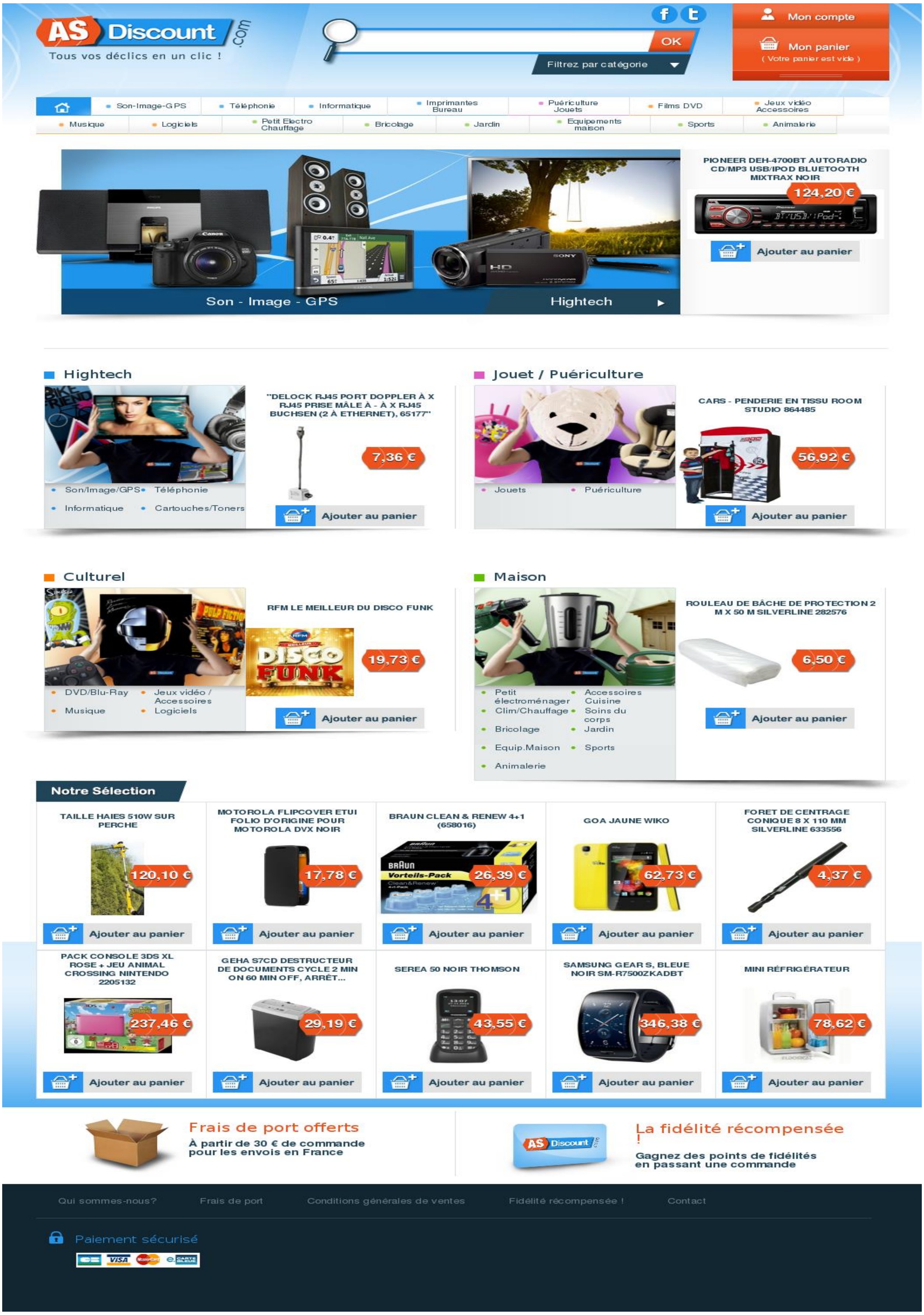


Figure 6.3 Homepage of site www.asdiscount.com, a representative of the e-commerce category.

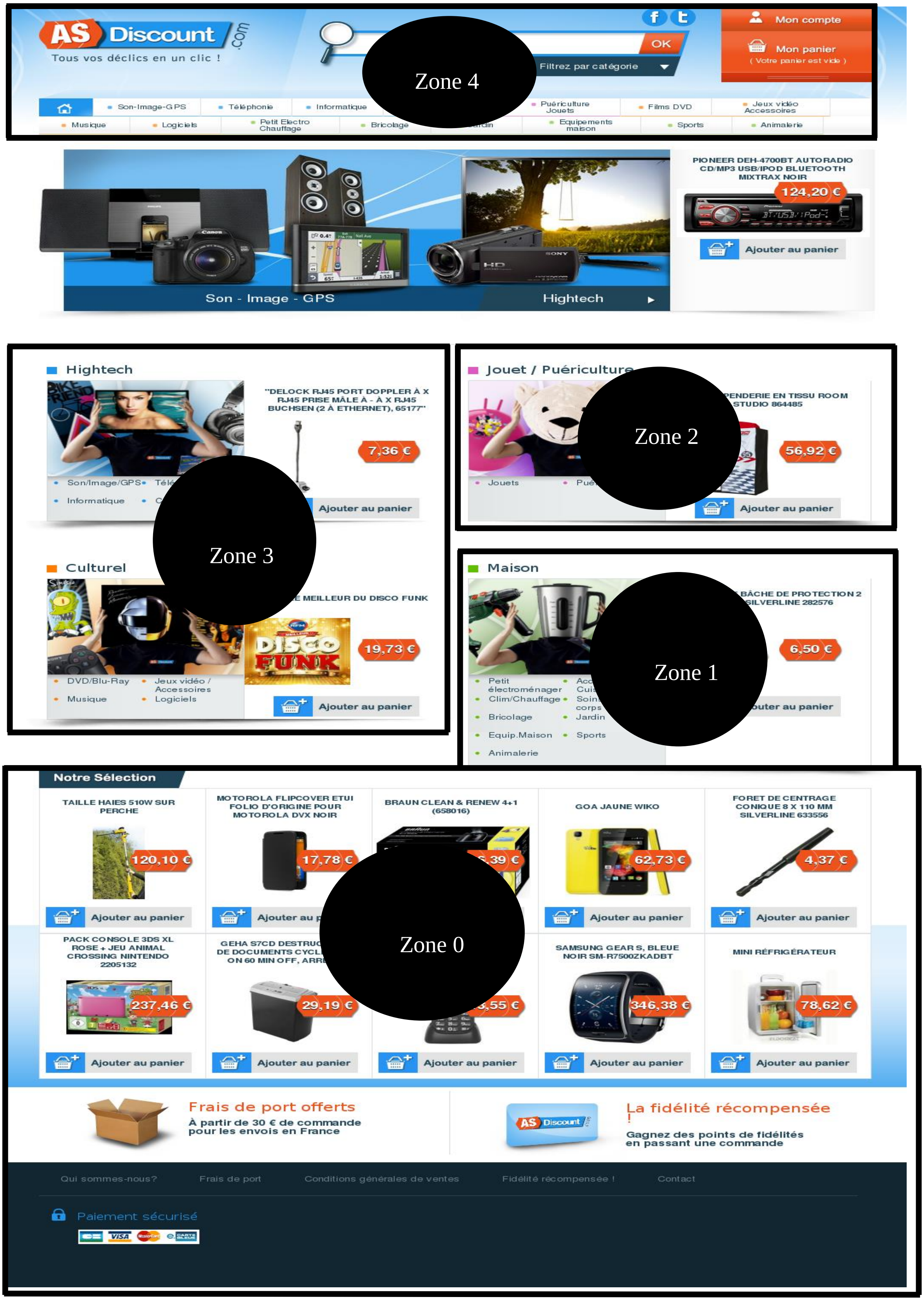


Figure 6.4 Segmenting the web page representative of the e-commerce category.

Figure 6.5 The homepage of site www.fdlm.org, a representative of the news category.

Figure 6.6 Segmenting the web page representative of the news category.

In the previous figures, it is noticeable that the rectangular shapes resulted from the agglomerative graph-based clustering algorithm are different in sizes (surfaces), lengths, widths, locations, orientations, and they have different spatial relations. It is noticeable also that the segmentation results contain some errors in some cases. For example, in figure 6.2, the header phrase "EXCURSION VISITE DES CHATEAUX DE LA LOIRE" existed in bottom of zone 4, but it should be in zone 2. Another example, in figure 6.6, there is a list of HTML items with the header title "ARCHIVES". The segmentation algorithm divides this list of items in two zones (zone 1 and zone 0), while the algorithm should keep this list of items as one block of items. As already mentioned, these types of errors indicate the necessity to enhance the suggested algorithm to obtain better results.

The obtained results have been adapted manually a little to be coherent with previous studies and recommendations for rendering forms and non-visual navigation on touch-screen devices [Giudice et al., 2012] [INSHEA, 2003] [Levesque et al., 2008] [Hayward et al., 2000] [Ebina et al., 1998]. Depending on these studies and recommendations, the minimum width between each two lines is 6 mm. All the shapes are far from the borders of the touch-screen device at least 1 mm. Figures 6.7, 6.8, and 6.9 present the adapted results for the segmented representative web pages of categories touristic, e-commerce, and news respectively. These adapted segmentation results have been viewed on a tablet Samsung GALAXY Tab 2. In figure 6.7, some dimensions of the last two horizontal rectangles have been extended to represent more surface on the touch screen device.

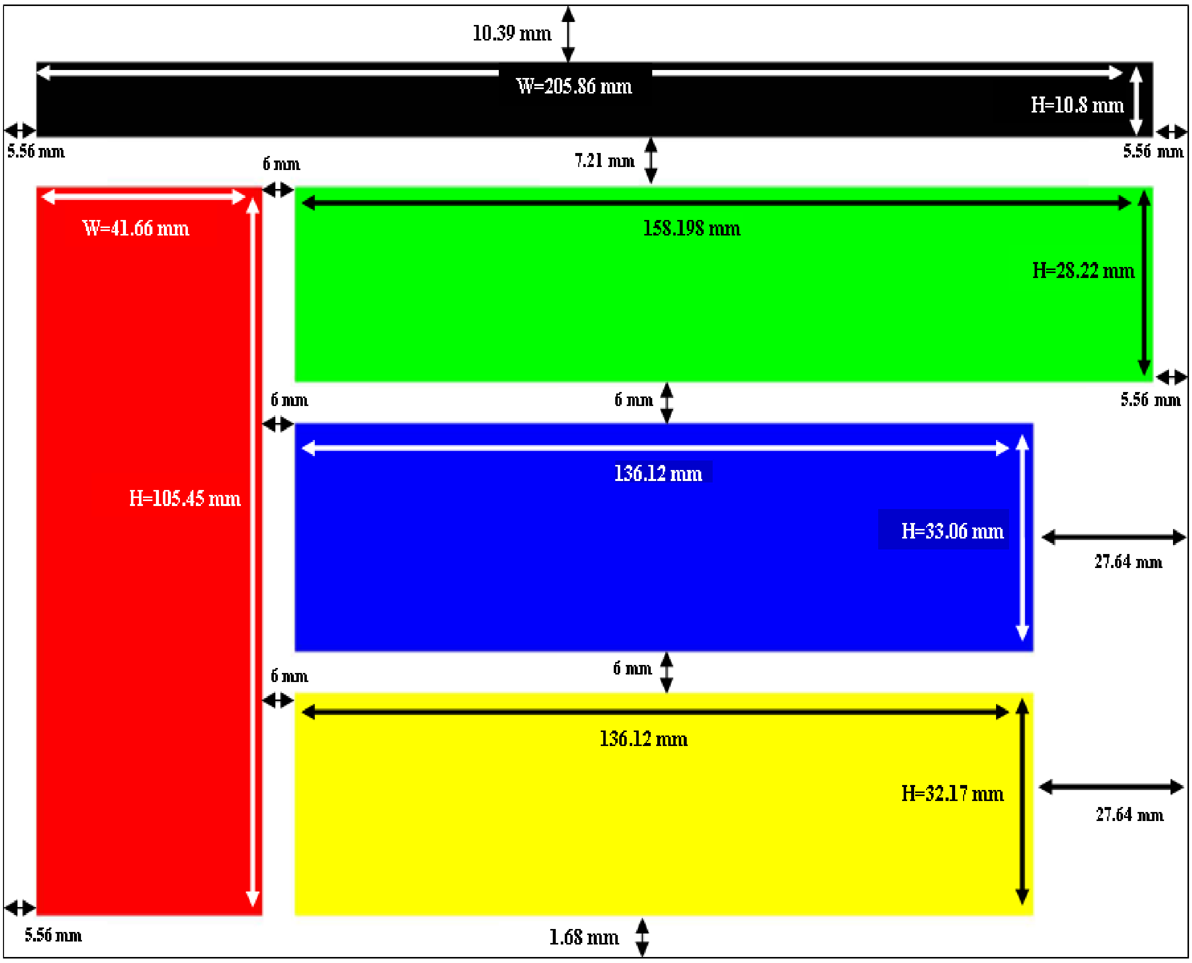


Figure 6.7 Adapted Segmentation of the web page representative of the touristic category.

There is no semantic meaning for the colors in figure 6.7 and in next figures. It is only a way to differentiate easily the zones.

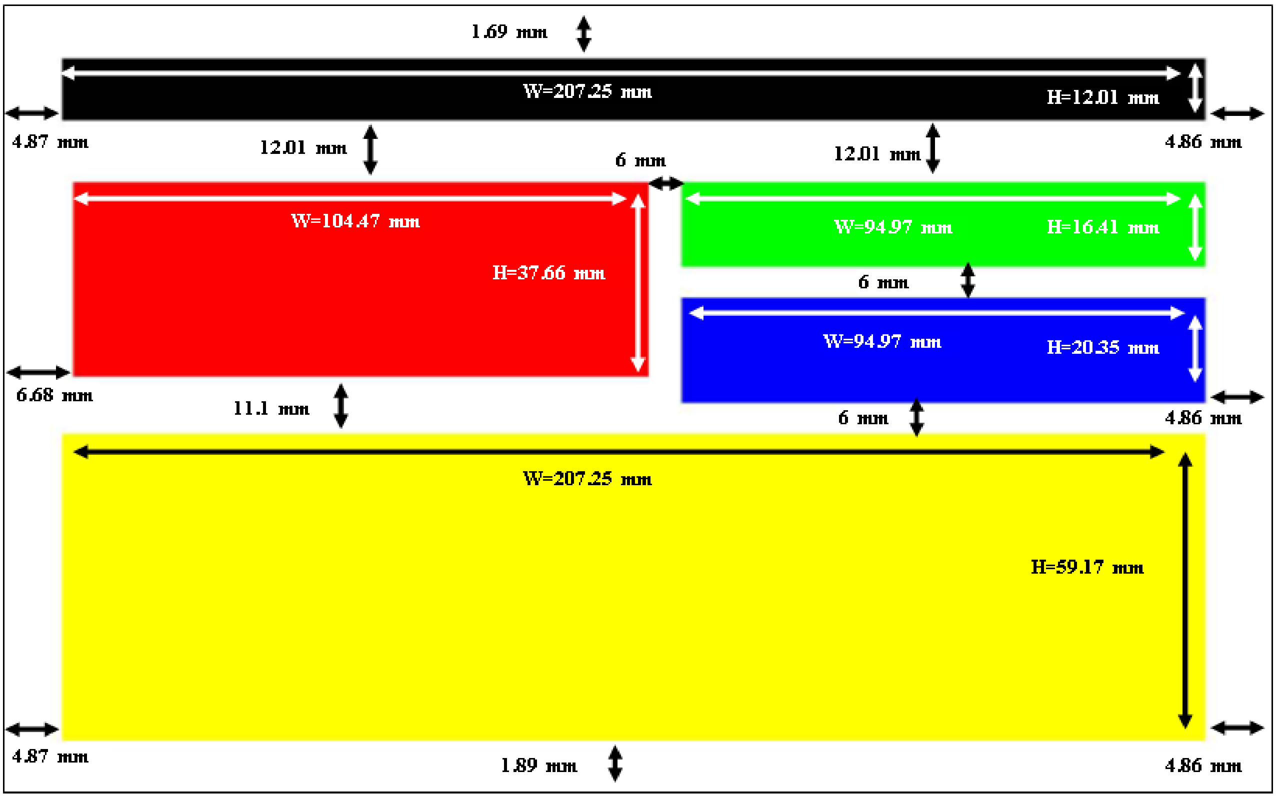


Figure 6.8 Adapted Segmentation of the web page representative of the e-commerce category.

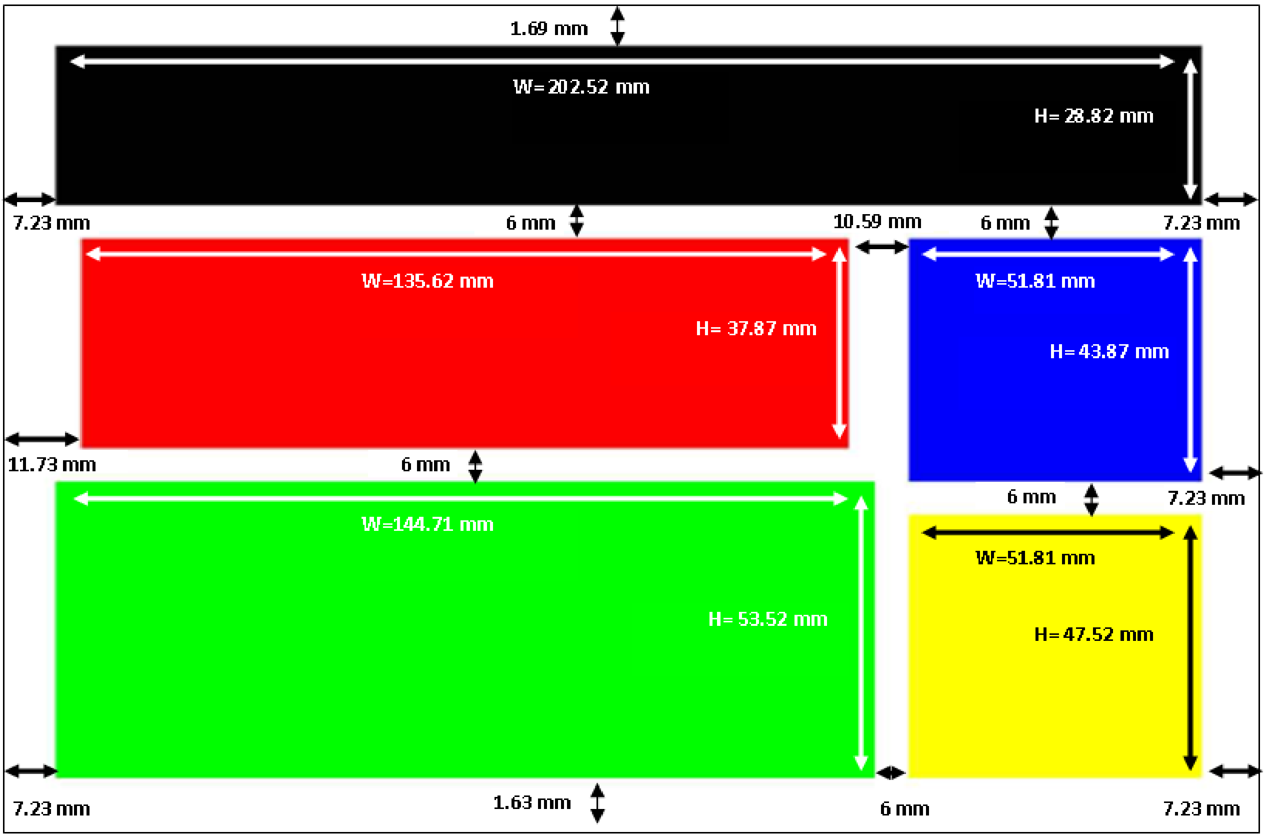


Figure 6.9 Adapted Segmentation of the web page representative of the news category.

After adapting manually the shapes of each representative web page, a particular vibro-tactile feedback should be dedicated for each shape. These vibro-tactile feedbacks could be varied in frequency, amplitude, waveform, and duration. The designed device TactiNET (hardware details are presented in chapter 3) can control only the frequency and the amplitude values of the used actuators. So the contents of all the graphical forms will be represented in vibration mode by controlling frequency and amplitude parameters.

In this phase, the most important question is "how to extract and to represent semantically the contents of each shape (segment) as vibration signals?". In other words, "how to convert automatically the semantic meaning of each segment of a web page into frequency and amplitude values". Extracting and representing the semantic meaning of contents is a critical point in the designed approach. During preparing the experiment, many methods have been proposed and implemented to extract and represent the semantic meaning of each segment.

One of proposed approaches was relating the number of HTML elements and the sum of surfaces of HTML rectangular bounding boxes in a segment to the amplitude and frequency values for representing this segment.

F(N° of HTML elements, sum of surfaces of HTML elements) = (frequency, amplitude)
or
F(N° of HTML elements, sum of surfaces of HTML elements) = (amplitude, frequency)

This propose is based on two ideas:

- the number of HTML elements in a segment is an indicator of amount of information inside it [Harper et al., 2013] [Cormier et al., 2016] [Deng et al., 2003],
- the segment size (the sum of surfaces of HTML elements inside a segment) is an indicator of its importance [Cormier et al., 2016] [Deng et al., 2003].

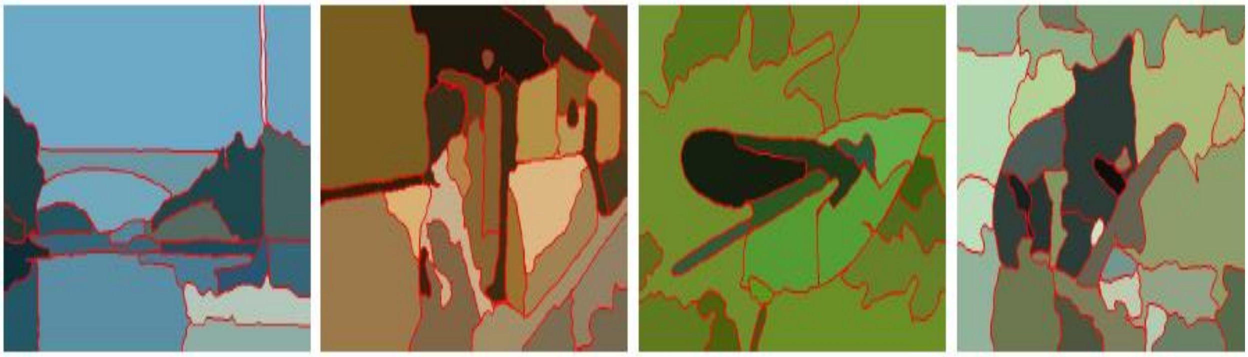
This option has been canceled because the piece of information about the sum of surfaces of HTML rectangular bounding boxes is already represented by the total size of the segment (the surface of the rectangular that represents it). In addition, this option does not support any importance for the textures of web page elements that are very important in perceiving the visual appearance of the web page [Harper et al., 2013] [Petit et al., 2011].

The focus was then oriented to a method that supports more information about the texture of each segment, and supports information about the variations of textures between the segments.

The texture is defined as a regular repetition of an element or pattern on a surface [Srinivasan et al., 2008]. Image textures are complex visual patterns composed of objects, entities or regions with sub-patterns with different characteristics of shape, color, brightness, size, density, and arrangement [Srinivasan et al., 2008]. Textures are rich sources of visual information [Materka et al., 1998] [Weszka et al., 1976]. In addition, the texture can be considered as a method of similarity grouping in an image [Weszka et al., 1976]. Figure 6.10 presents some examples of segmenting images into uniform blocks depending on the textures [Pappas et al., 2009] [Mobahi et al., 2011].

(a) An original image, and its texture-based segmentation [Pappas et al., 2009].

(b) Original images [Mobahi et al., 2011].



(d) Texture-based segmented images [Mobahi et al., 2011].

Figure 6.10 Segmenting images into uniform blocks [Pappas et al., 2009] [Mobahi et al., 2011].

It is clear in the images presented in figure 6.10 that segmenting the main parts of an image depending on their textures is possible. This could be generalized to the web pages. The whole web page structure could be perceived as a set of segments varied in textures. So perceiving the differences in visual textures between the web page segments helps in perceiving visually its global structure. This idea could be transformed into tactile format. Perceiving the variances in tactile textures between the web page segments helps to perceive its global structure.

One of important features of the texture is the contrast [Gebejes et al., 2013]. Contrast in an image is defined as the difference in visual properties such as luminance or colors that makes an object (or its representation in an image or display) distinguishable in the image [Campbell et al., 1968]. Designers of web pages usually use the concepts of contrasts to enhance the visual hierarchy of the designed web pages. So the focus was oriented to a method that transfers the visual contrasts of web pages segments into tactile contrasts.

Standard deviation was the chosen measure to represent the contrast of visual elements in each segment. This option has been chosen depending on the state of the art for measuring the contrast in images [Campbell et al., 1968] [Gebejes et al., 2013] [Kumar et al., 2012]. The standard deviation of pixels in a segment indicates the degree of variability of gray-scale values in that segment. The more visual contrast in an image, the more the standard variation value is greater. Figure 6.11 presents an example of two shapes that have identical centric regions with different gray-scale values of the surrounding regions.

(a) A center region with a dark surrounded area (b) A center region with bright surrounded area
Figure 6.11 Identical centric regions with different gray-scale values of the surrounding regions.

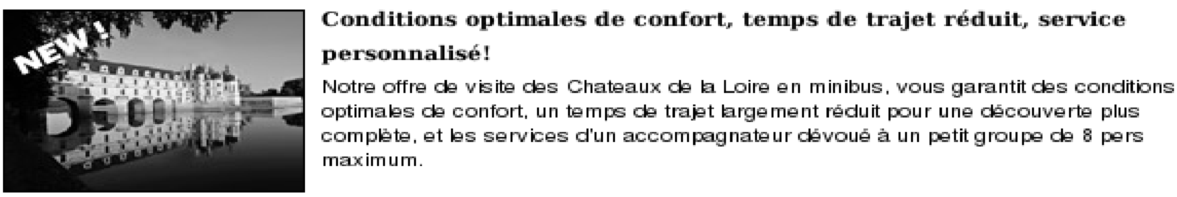
The centric region surrounded by a dark area presented in figure 6.11(a) is perceived brighter than the same centric region surrounded by a light area presented in figure 6.11(b). The standard deviation of the figure 6.11(a) is 39.1970, while the standard deviation of the figure 6.11(b) is 17.5496. This difference in the standard deviation values is due to the greatest contrast in the figure 6.11(a) comparing with the contrast in the figure 6.11(b).

The value of standard deviation SD in an image I is calculated by the following formulate [Kumar et al., 2012]:

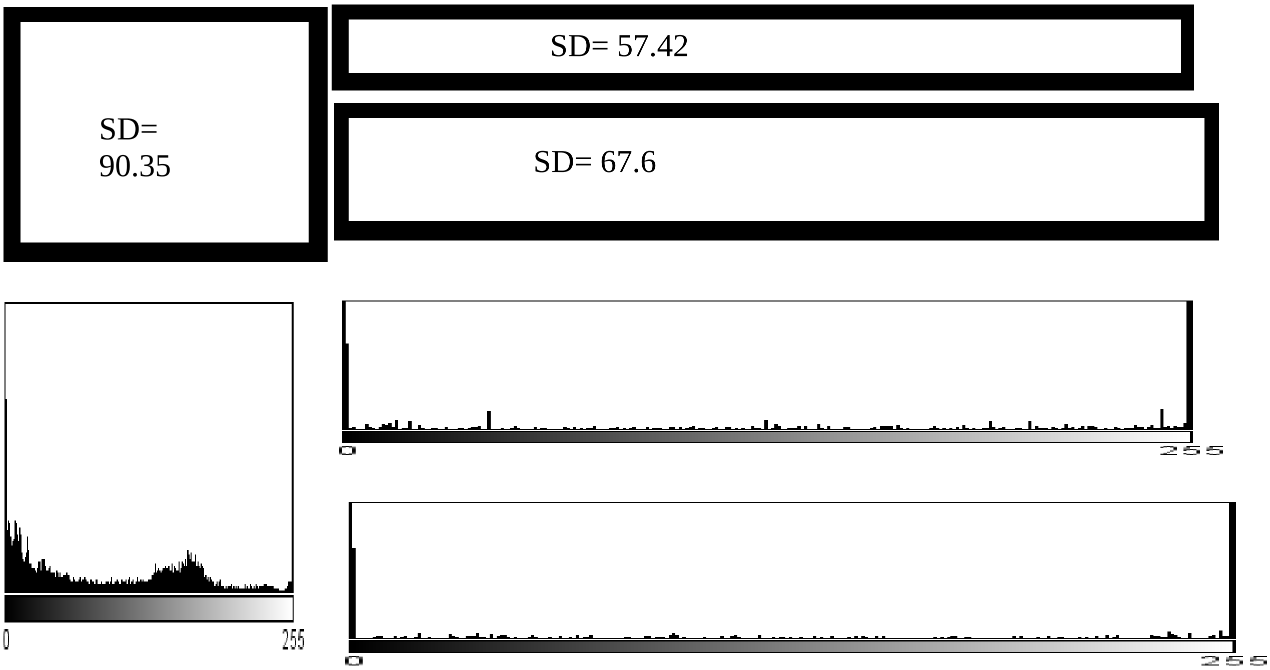
$$SD = \sqrt{\frac{1}{N\text{x}M}\sum_{i=1}^{N}\sum_{j=1}^{M}\left(x_{ij} - \mu\right)^2}$$

N, M are the numbers of rows and columns in the image I. x_{ij} indicates the gray scale value of the pixel ij. μ is the mean of gray scale values of all the pixels in the image I [Kumar et al., 2012].

Supporting information about the variances in contrast between the elements of an image provides an indicator about the structure and the spatial relationships between the elements in this image. This idea could be generalized to the web pages and other numerical documents. For example, figure 6.12(a) views a segment of a web page www.francetourisme.fr that contains a header, a paragraph, and an image. The values of standard deviation (contrast value) for the header, the paragraph, and the image are respectively 57.42, 67.6, and 90.35. These values and the histogram of each part are presented in figure 6.12(b). Mapping these values to vibration variances indicates that this segment of web page consists of different parts with different contrast values. In figure 6.2, and in next figures, the histogram is viewed for each part in order to analyze if there are special distinguishable properties for the histogram of each part.



(a) A part of a web page www.francetourisme.fr.



(b) Values of standard deviation and the histogram for each element in a part of the web page.
Figure 6.12 Standard deviation values for a segment in the home web page www.francetourisme.fr.

The value of standard deviation for the header is 57.42. But, the value of standard deviation for the header and the paragraph together is 66.13, and the value of standard deviation for the header, the paragraph, and the image together is 87.32. This change in standard deviation values indicates a changing in the contrast between the elements of the segment, and this refers to different structures.

In figure 6.12, it is noticeable that the histogram of the image part has less peaks than the histograms of the textual parts. This difference in distribution could be useful in next versions of the system to distinguish easily between the texts and the images in a web page.

To calculate the standard deviation for each segment in the representative web pages, the representative image of each segment has been transformed into gray-scale format. Then the standard deviation formulate has been applied on the transformed gray-scale images. In appendix D, figures D.1, D.2, and D.3 present the transformed gray-scale images of representative web pages of categories touristic, e-commerce, and news respectively.

In order to represent the vibration feedback dedicated for each segment, the standard deviation value calculated for each segment has been assigned to the amplitude value (amplitude=SD), and a constant value 304.6875 Hz has been assigned to the frequency. This frequency value has been chosen depending on results of the experiment described in section 5.3 in chapter 5. Figures 6.13, 6.14, and 6.15 present the histogram and the amplitude values dedicated for each segment in representative web pages of categories touristic, e-commerce, and news respectively.

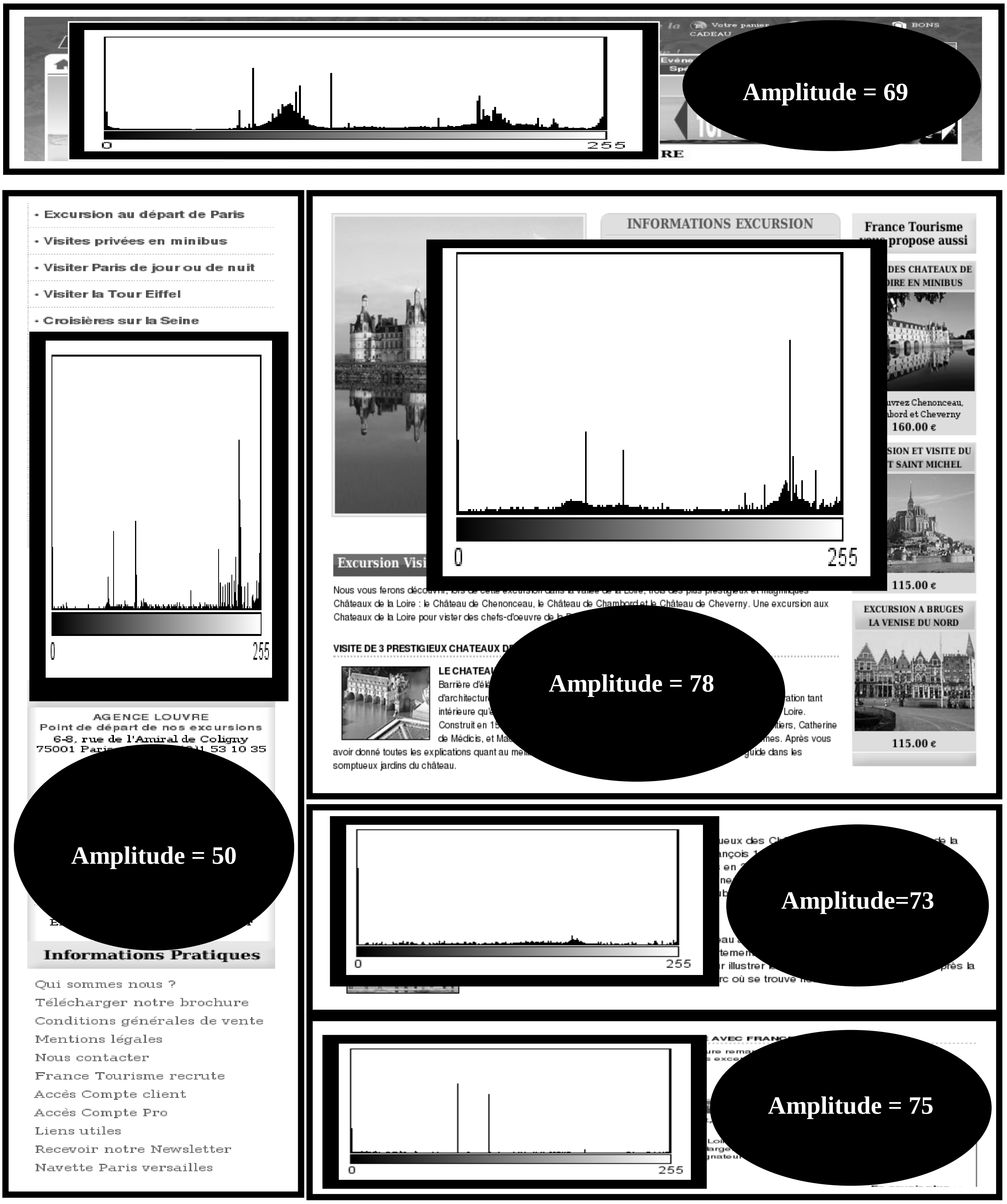


Figure 6.13 Standard deviation values (amplitude values) and the histograms of segments in the web page representative of the touristic category.

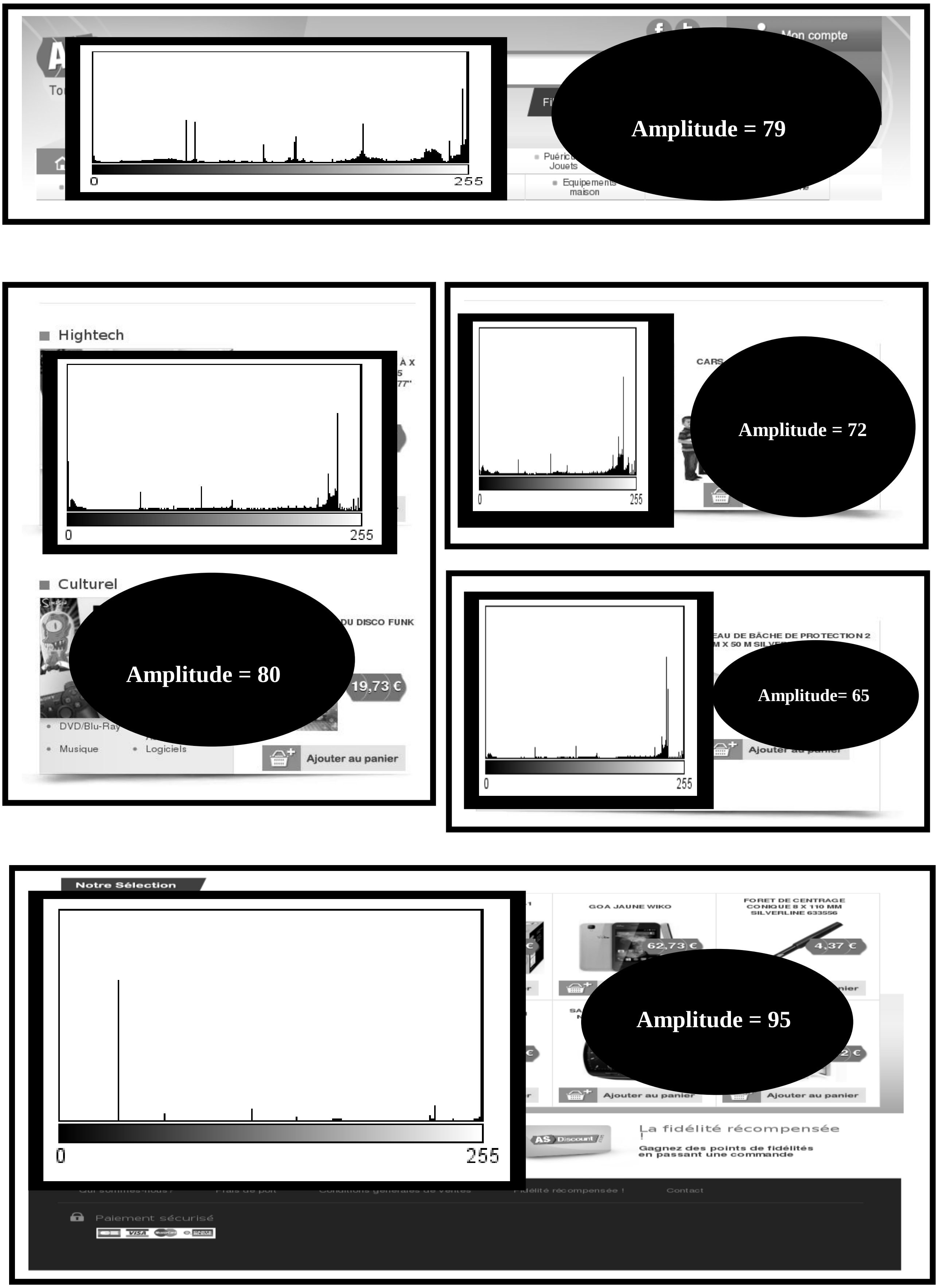


Figure 6.14 Standard deviation values (amplitude values) and the histograms of segments in the web page representative of the e-commerce category.

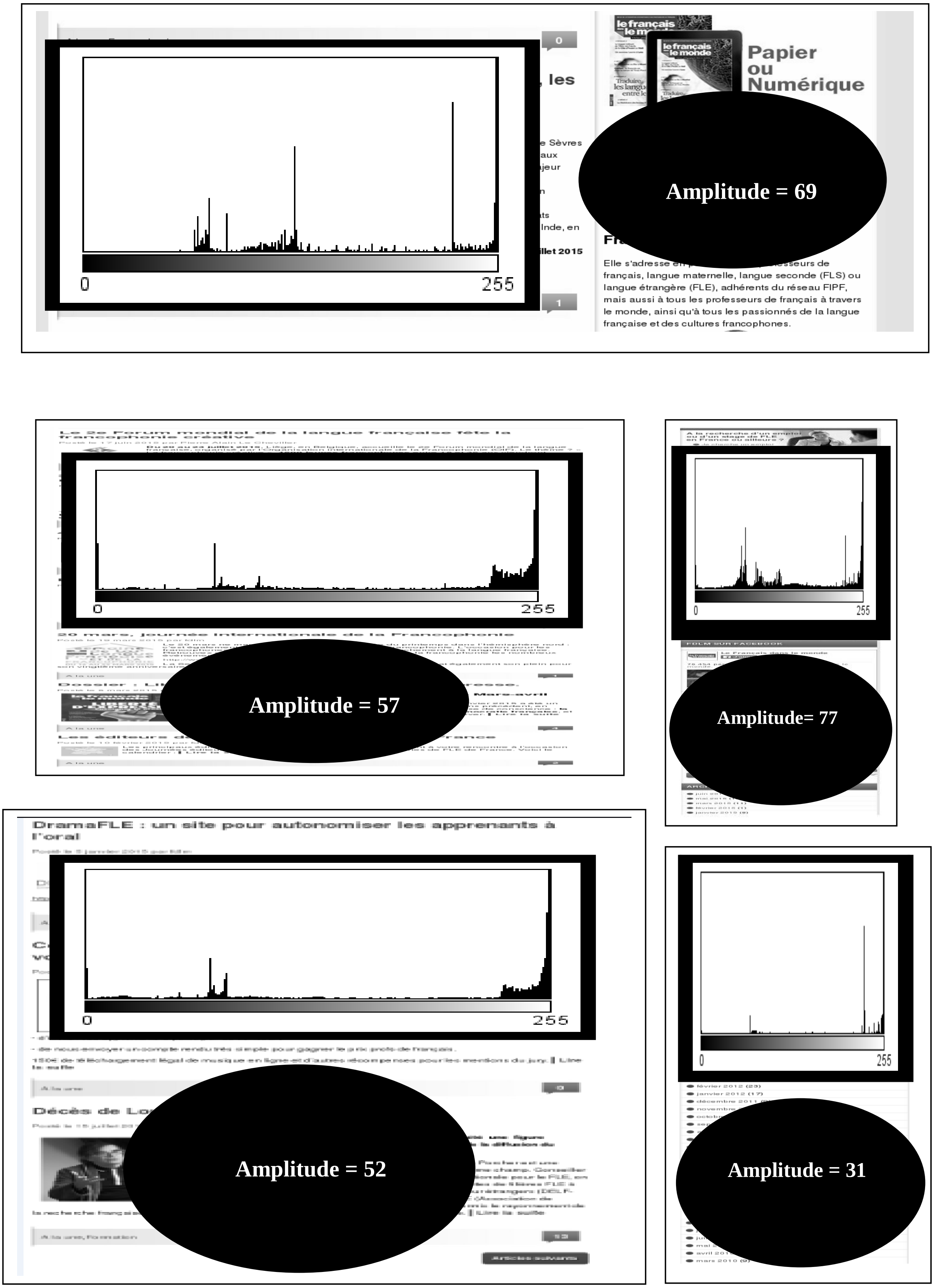
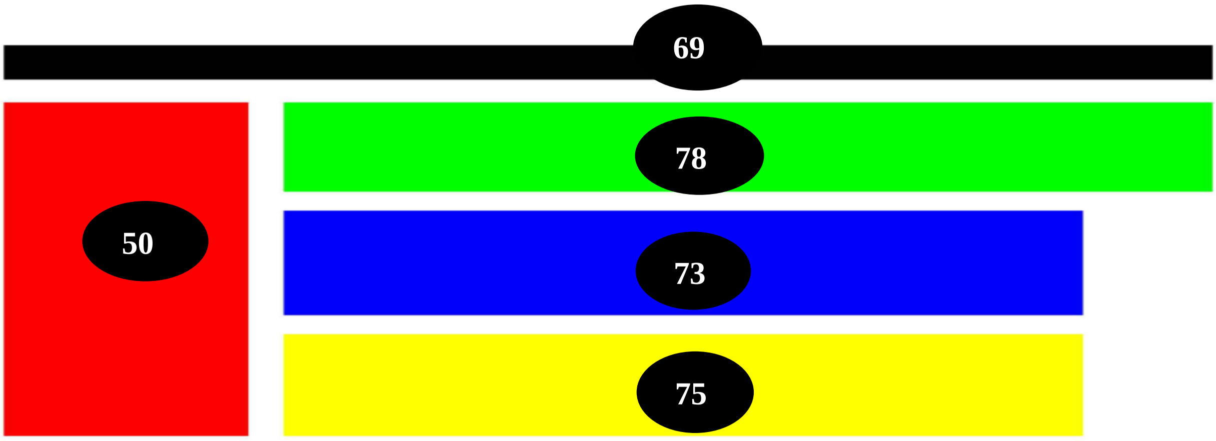
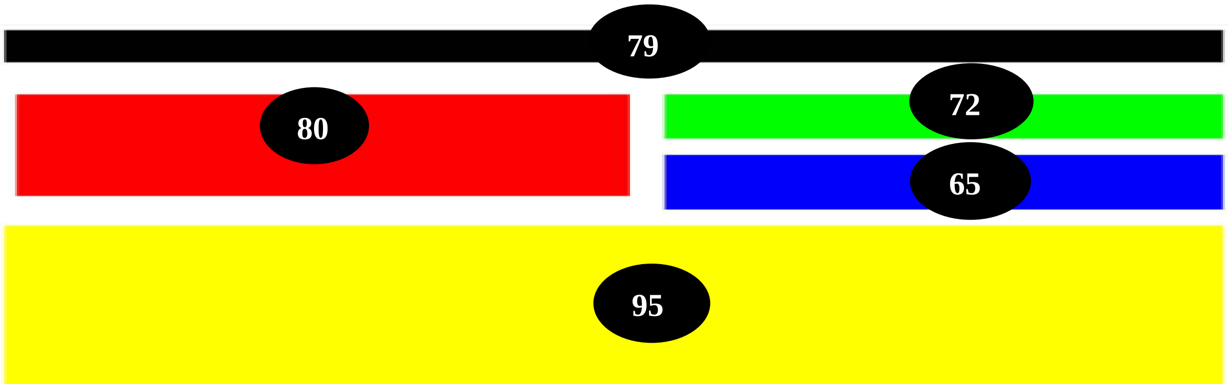


Figure 6.15 Standard deviation values (amplitude values) and the histograms of segments in the web page representative of the news category.

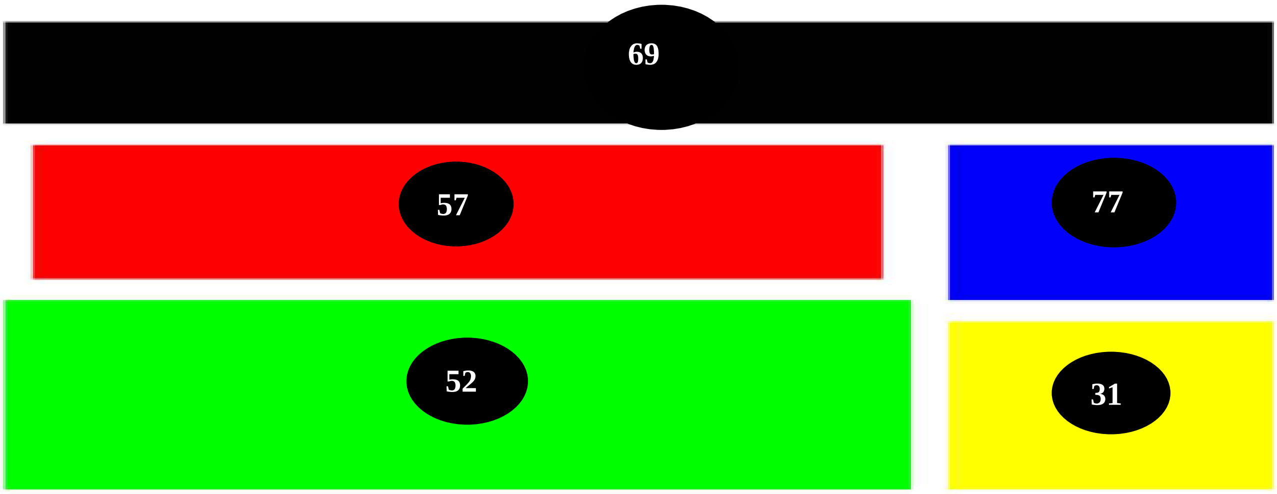
Last three figures confirmed the previous mentioned notice that the histograms of the image parts have less peaks than the histograms of the textual parts. Figure 6.16 presents the adapted segmented structures of the representative web pages of categories touristic, e-commerce, and news respectively with their associated amplitude values.



(a) The adapted segmented structure of the representative web page of the touristic category with the associated amplitude values.



(b) The adapted segmented structure of the representative web page of the e-commerce category with the associated amplitude values.



(c) The adapted segmented structure of the representative web page of the news category with the associated amplitude values.

Figure 6.16 The adapted segmented structures of the representative web pages of categories touristic, e-commerce, and news with their associated amplitude values.

Table 6.1 presents a summary of amplitude values for each representative web page. For each web page the minimum, the maximum, and the mean amplitude (contrast) values are represented.

Table 6.1 Minimum, maximum, and mean amplitude (contrast) values.

Web page type	**Amplitude values (contrast values)**	**Minimum amplitude value**	**Maximum amplitude value**	**Mean amplitude Value**
touristic	69 50 78 73 75	50	78	69
e-commerce	79 80 72 65 95	65	95	78.2
news	69 57 52 77 31	31	77	57.2

In section 5.4 of the fifth chapter, it was found that the ranges of amplitudes close to value 55 are more discriminated than ranges of amplitudes close to other amplitudes such as 155 and 255. It is noticeable in table 6.1 that the mean amplitude values (69, 78.2, 57.2) are little close to the value 55.

To summarize what has been presented in section 6.2:

1. a dedicated algorithm has been run on a corpus of 900 web pages in order to extract three representative web pages of different categories,
2. the three extracted representative web pages have been segmented automatically,
3. the three segmented web pages have been converted semi-automatically into 3 vibrating patterns of 5 zones.

The three vibrating patterns will be used in the next experiment that aims to examine the performance of sighted and blind persons in recognizing the structures of web pages.

6.3 Protocol of the experiment

Each experiment (either with sighted or blind persons) consists of a series of tests to navigate two touched-screen tablets, and to compare the web pages structures presented on the two tablets, then to decide if the two navigated web pages structures are identical or not. Two prototype devices of TactiNET (detailed in section 3.4 of the third chapter) have been used for this experiment. The participant navigates the first tablet with one of his/her index fingers, and puts the another index finger on the actuator to perceive the vibrations. The participant then navigates the second tablet with one of his/her index fingers, and puts the another index finger on the actuator to perceive the vibrations. After navigating the two devices, the participant decides if the two structures are identical or not, and then starts redrawing the discovered web pages structures on A4 paper.

To run the experiment, four tablets have been used. Two of type Samsung GALAXY Tab 2 (10.1 inch) [Samsung_galaxy_tab_2, 2016], and two of type Samsung Galaxy Tab S (10.5 inch) [Samsung-galaxy-tab-s, 2016]. Two tablets of different types have been used for each web page structure. The first tablet Samsung GALAXY Tab 2 (10.1 inch) [Samsung_galaxy_tab_2, 2016] is dedicated to be used by the participant, and connected with the prototype device of TactiNET. The second tablet Samsung Galaxy Tab S (10.5 inch) is dedicated to be used by the experimenter. The two tablets are connected by a Bluetooth connection.

Two Android interfaces have been designed to be installed on the two tablets and to be used by the experimenter and the participant. The first interface dedicated to the experimenter allows controlling the experiment by connecting the two interfaces and transferring information between them. The experimenter can select which web page category to be presented on the another tablet; the frequency value (101.5625Hz, 203.125Hz, 304.6875Hz, 406.25Hz, or 500 Hz), and the amplitude values for each stimulus (either a fixed amplitude 55 for all the segments or different amplitude values represent the standard deviation for each segment). Figure 6.17 presents a part of the experimenter interface.

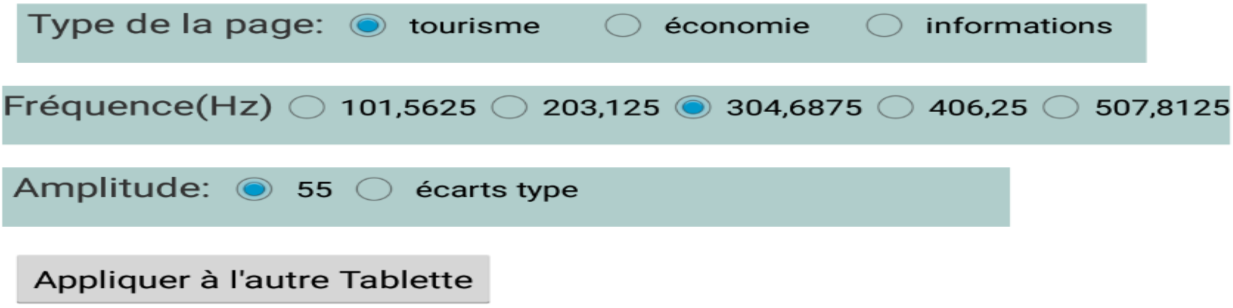


Figure 6.17 A part of the experimenter interface.

The second interface is dedicated to the participant. It views the web pages structures selected by the experimenter. These web pages structures were presented in figures 6.7, 6.8, and 6.9. When the participant touches a segment on the touched-screen, the actuator generates vibration feedbacks with a frequency 304.6875 Hz and with an amplitude value dedicated for this segment.

36 tests of structures comparison have been achieved by each participant. 3 comparisons of identical structures (touristic ↔ touristic, e-commerce ↔ e-commerce, and news ↔ news), and 3 comparisons of different structures (touristic ↔ e-commerce, touristic ↔ news, and e-commerce ↔ news). The total number of identical and different structures comparisons is 6 as indicated in the table 6.2.

Table 6.2 Identical (I) and different (D) structures comparisons.

	Touristic	E-commerce	News
Touristic	I	D	D
E-commerce		I	D
News			I

These 6 comparisons have been repeated 3 times with fixed amplitude value equals 55, and repeated 3 times with variant amplitude values (standard deviation values). The total number of tests is 36 (18 comparisons with a fixed amplitude value and 18 comparisons with variant amplitude values) as indicated in table 6.3.

Table 6.3 Details of structures comparisons.

	Fixed Amplitude 55			Variant Amplitude		
	Touristic	**E-commerce**	**News**	**Touristic**	**E-commerce**	**News**
Touristic	I (3)	D(3)	D(3)	I(3)	D(3)	D(3)
E-commerce		I(3)	D(3)		I(3)	D(3)
News			I(3)			I(3)

The average time of the experiment is 90 minutes. All the experiments with blind and sighted participants have been filmed in order to analyze and understand more their navigation strategies.

6.4 Participants in the experiment

A group of sighted and blind persons has participated in this experiment. 11 persons have participated in this experiment. 5 of them are sighted, and 6 are blind. The experiments with blind participants have been organized by the association Cécitix [Cécitix, 2016]. All the tests in this experiment have been conducted in collaboration with PALM laboratory [PALM-Unicaen, 2016] [Guilbert, 2015] with a strong interaction with me to build and to program the experimental device.

The 6 blind participants (3 males and 3 females) are different in the date of their vision loss. 3 of them (50%) have a congenital vision loss (since birth), and the other 3 participants (50%) have adventitious vision loss (after birth). The average of ages for the blind participants is 54.8 years. 5 of them have participated in the second experiment that concerns selection the most perceptible and discriminated ranges of amplitudes (cf. chapter 5, section 5.4). All the sighted participants are females. Their average of ages is 26.4 years. Table 6.4 presents the information related for each participant.

Table 6.4 The detailed information about the participants.

Subject id	Vision status	Age (years)	Sex	Date of the blindness	Participation in previous experiments
D1	blind	55	Female	congenital vision Loss	yes
D2	blind	66	Male	congenital vision Loss	yes
D3	blind	39	Female	8 years	yes
D4	blind	40	Male	congenital vision Loss	no
D5	blind	69	Female	32 years	yes
D6	blind	60	Male	27 years	yes
V1	sighted	27	Female	---	no
V2	sighted	26	Female	---	no
V3	sighted	25	Female	---	no
V4	sighted	29	Female	---	no
V5	sighted	25	Female	---	no

Blind participants have been asked to provide some technical information about their experience in dealing with computer operating systems, and screen readers. 5 of the participants use regularly fixed or portable personal computers. The used operating system in all the cases is Windows. The used screen readers are JAWS (Job Access With Speech) and NVDA (NonVisual Desktop Access). Only one participant (Id: D3) uses a touch-screen mobile device to navigate the Web. The used mobile device is iPhone supported by Voiceover screen reader. 3 of the participants use regularly their personal computers more than 8 hours per day, and 2 of them use their personal computers 1-2 hours per day. Table 6.5 presents more information about the operating systems and screen readers used by blind participants.

Table 6.5 Operating systems and screen readers used by blind participants.

Subject id	Used operating system	Used screen reader	Using Personal computers
D1	Windows8	JAWS	1-2 hours per day
D2	Windows	NVDA	8 hours per day
D3	Windows7	JAWS	10 hours per day
D4	---	---	---
D5	Windows	NVDA	1-2 hours per day
D6	Windows7	JAWS	10 hours per day

6.5 Analysis the results of the experiment

Each participant has answered 36 questions about the similarity or dissimilarity of two navigated structures. The proposed question is "can you indicate, as quick as possible, if the two spatial structures are identical?". Tables 6.6, 6.7, 6.8, and 6.9 present numbers of correct answers for the blind and sighted participants for the fixed and variable amplitude values. In next tables, there are the following symbols:

- N↔N: comparing two similar structures of type news.
- E↔E: comparing two similar structures of type e-commerce.
- T↔T: comparing two similar structures of type tourism.
- N↔E: comparing two dissimilar structures of types news and e-commerce.
- N↔T: comparing two dissimilar structures of types news and tourism.
- E↔T: comparing two dissimilar structures of types e-commerce and tourism.

Table 6.6 N° of correct answers while comparing similar and dissimilar structures by the blind participants (fixed amplitude 55).

	Fixed Amplitude 55							
	Similar structures			Dissimilar structures				
Subject ID	N↔N	E↔E	T↔T	N↔E	N↔T	E↔T	Total correct answers	Percentage of correct answers
D1	0	0	0	3	3	3	**9**	**50,0%**
D2	0	1	2	2	2	3	**10**	**55,6%**
D3	3	3	3	2	3	2	**16**	**88,9%**
D4	2	1	3	3	3	2	**14**	**77,8%**
D5	1	1	0	1	2	3	**8**	**44,4%**
D6	1	0	1	2	3	2	**9**	**50,0%**
Total	**7**	**6**	**9**	**13**	**16**	**15**	**66**	**61,1%**
	38,9%	**33,3%**	**50,0%**	**72,2%**	**88,9%**	**83,3%**	**61,1%**	
Total correct answers	**22**			**44**				
Percentage of correct answers	**40,7%**			**81,5%**				

Tables 6.7 N° of correct answers while comparing similar and dissimilar structures by the blind participants (variable amplitude).

	Variable Amplitude							
	Similar structures			Dissimilar structures				
Subject ID	N↔N	E↔E	T↔T	N↔E	N↔T	E↔T	Total correct answers	Percentage of correct answers
D1	0	0	2	3	3	3	11	61,1%
D2	0	2	3	2	3	2	12	66,7%
D3	3	2	3	2	3	3	16	88,9%
D4	3	2	3	2	2	2	14	77,8%
D5	1	0	0	3	3	3	10	55,6%
D6	2	1	0	2	1	1	7	38,9%
Total	9	7	11	14	15	14	70	64,8%
	50,0%	38,9%	61,1%	77,8%	83,3%	77,8%	64,8%	
Total correct	27			43				
Percentage of correct answers	50,0%			79,6%				

Tables 6.8 N° of correct answers while comparing similar and dissimilar structures by the sighted participants (fixed amplitude).

	Fixed Amplitude 55							
	Similar structures			Dissimilar structures				
Subject ID	N↔N	E↔E	T↔T	N↔E	N↔T	E↔T	Total correct answers	Percentage of correct answers
V1	0	2	0	2	1	2	7	38,9%
V2	1	0	0	3	3	3	10	55,6%
V3	3	1	2	3	3	3	15	83,3%
V4	0	3	1	3	3	2	12	66,7%
V5	1	2	1	3	2	2	11	61,1%
Total	5	8	4	14	12	12	55	61,1%
	33,3%	53,3%	26,7%	93,3%	80,0%	80,0%	61,11%	
Total correct	17			38				
Percentage of correct answers	37,8%			84,4%				

Tables 6.9 N° of correct answers while comparing similar and dissimilar structures for the sighted participants (variable amplitude).

	Variable Amplitude							
	Similar structures			Dissimilar structures				
Subject ID	N↔N	E↔E	T↔T	N↔E	N↔T	E↔T	Total correct answers	Percentage of correct answers
V1	3	1	2	3	2	3	14	77,8%
V2	1	1	0	3	3	3	11	61,1%
V3	1	2	2	3	3	3	14	77,8%
V4	0	1	2	1	1	2	7	38,9%
V5	1	0	0	3	2	3	9	50,0%
Total	6	5	6	13	11	14	55	61,1%
	40,0%	33,3%	40,0%	86,7%	73,3%	93,3%	61,1%	
Total correct	17			38				
Percentage of correct answers	37,8%			84,44%				

By analyzing the presented data, the following results could be concluded:

- there is not a noticeable difference in remarkable the structures between the blind and the sighted participants. The percentage of correct answers for the blind participants is 63%, while the percentage of correct answers for th sighted participants is 61.1%;
- concerning the sighted participants, there is not a remarkable difference in recognizing the structures by changing the amplitude values. The percentage of correct answers for the fixed and variable amplitude is 61.1%;
- in what concerns the blind participants, there is a little enhancement in recognizing the structures by changing the amplitude values. The percentage of correct answers for the fixed amplitude is 61.1%, while the percentage of correct answers for the variable amplitude is 64.8%;
- the best performance is assigned for the blind participant with id equals D3. This is probably due to the fact that this female participant was the only participant that has already used touched devices (an iPhone device supported by Voiceover). In addition to, she is the youngest between others blind participants. This indicates that the more the blind users are familiar with touch-screen techniques, the more they are able to use the designed system;
- the percentage of correct answers in recognition web pages structures for all the participants (blind and sighted) is 62.1%. The percentage of correct answers in recognition dissimilar structures for blind and sighted users is 82.47%. These percentages are promise, due to the following facts:
  - the experiments with sighted and blind participants have been conducted without any training period due to time-constraints. Training the participants on the system for a sufficient period enhances their performance in recognizing the web pages structures;
  - 5 of the 6 blind participants (83%) do not use touch-screen devices to navigate the Web. Using touch-screen devices to navigate the Web enhances their performance in dealing with the system;
  - many features of the designed system have not used yet in the conducted experiments, such using multi-touch techniques by integrating many vibrators.
- it is noticeable that the percentage of correct answers in comparing the dissimilar structures is higher than the accuracy percentage in comparing the similar structures as presented in figures 6.18 and 6.19. This concludes that the participant answers that two structures are similar only if he/she is absolutely sure of his/her answer; but when the participant has a doubt about the correct answer, he/she chooses that the two structures are not similar.

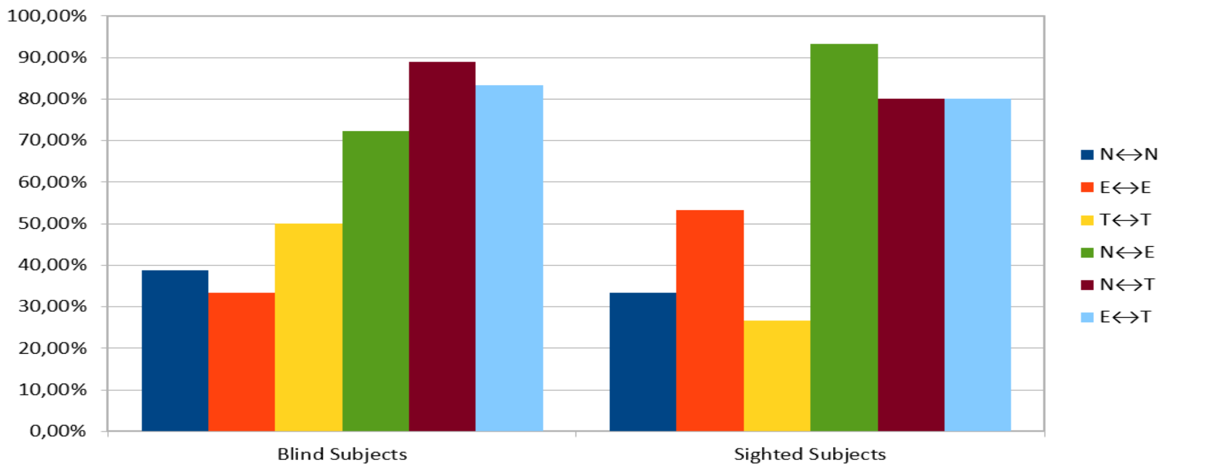


Figure 6.18 Percentage of correct answers in comparing the similar and dissimilar structures with fixed amplitude (55).

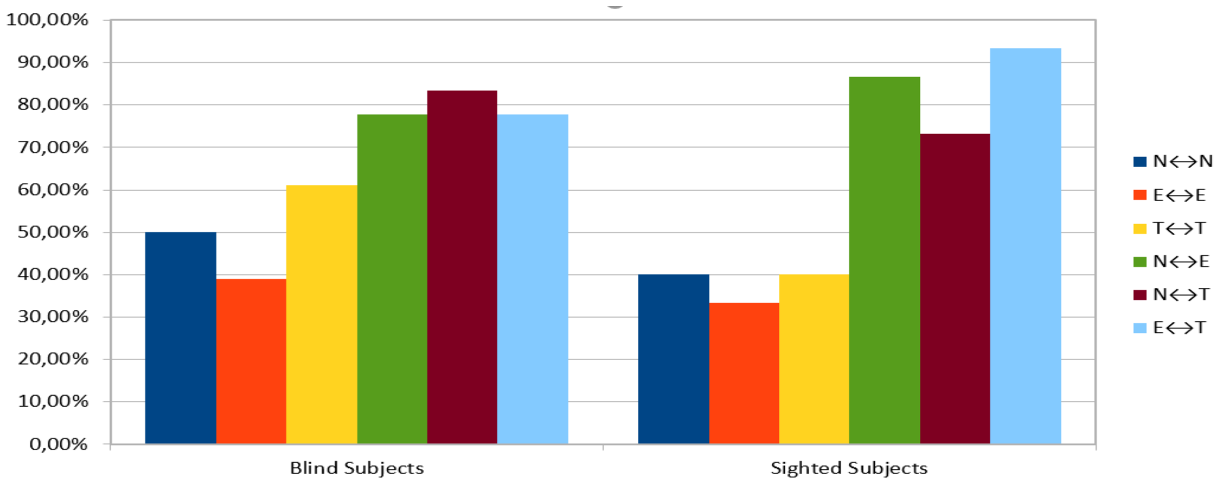


Figure 6.19 Percentage of correct answers in comparing the similar and dissimilar structures with variable amplitudes.

It is noticeable in figures 6.18 and 6.19 that the best performance of blind participants is in recognizing the similar structures of the touristic category.

To analyze the differences in performance between participants who have congenital vision loss (since birth) comparing to the whole participants, the percentage of correct answers while comparing the similar and dissimilar structures have been calculated. Table 6.10 presents these percentages.

Table 6.10 Differences in performance between participants who have congenital vision loss and those who have adventitious vision loss.

	Fixed Amplitude (55)		**Variable Amplitude**	
	Similar Structures	**Dissimilar Structures**	**Similar Structures**	**Dissimilar Structures**
All blind participants	40.7%	81.5%	50.0%	79.6%
Participants who have congenital vision loss	50.0%	86.1%	63.9%	83.3%

D3 has a vision loss since she was 8 years old; so she was considered between the participants who have congenital vision loss (D1, D2, D3, and D4. It is noticeable in table 6.10 that the percentages of correct answers for participants who have congenital vision loss are better than the total percentages of correct answers for all the blind participants. These results may indicate that the persons who have congenital vision loss may be more familiar with the designed system more than persons who have adventitious vision loss.

After answering questions about recognizing the structures, each participant has been asked to redraw 2 of the three representative web pages. One of the subjects (ID: D6) has refused to participate in this phase of the experiment.

The redrawing procedure has been achieved as following:

- the experimenter presents a web page structure on the tablet;
- the participant navigates the table; and
- the participant redraws the navigated structure on a A4 paper.

After analyzing the redrawn images, the following observations have been found:

- in what concerns the blind participants:
    - three of the blind participants (users with IDs: D1, D4, and D5) redrew the presented structures as horizontal and vertical lines (cf. figure 6.20). No one of them redrew rectangular shapes as presented in the structures viewed on the tablet. This indicates that these three participants did not perceive the structure as a set of separated (disconnected, distinct, distinguished) rectangular blocks of vibrations, but they perceived the structure as a series of sequences of continuous vibrations organized linearly either horizontally or vertically.

Figure 6.20 a) The original structure of the representative web page of the e-commerce category.

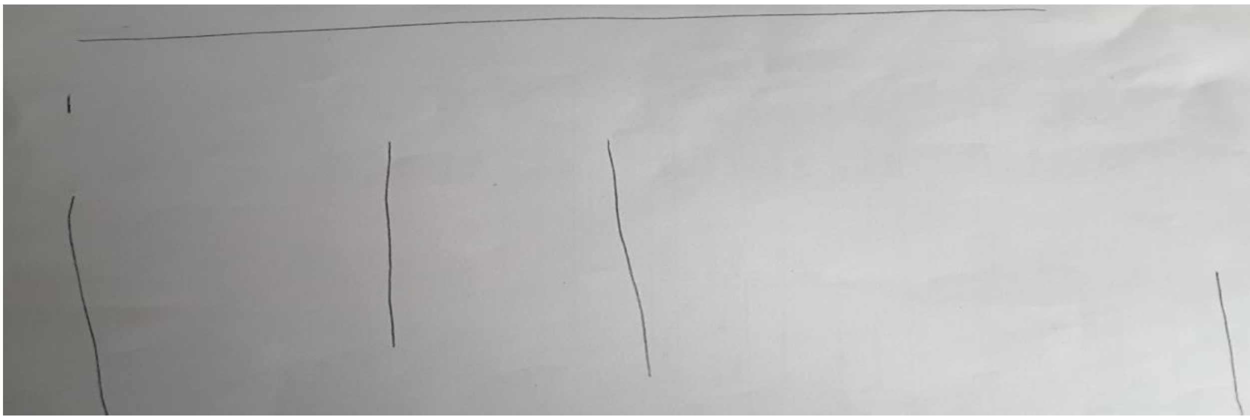


Figure 6.20 b) A redrawn structure of the representative e-commerce category (Subject D1).

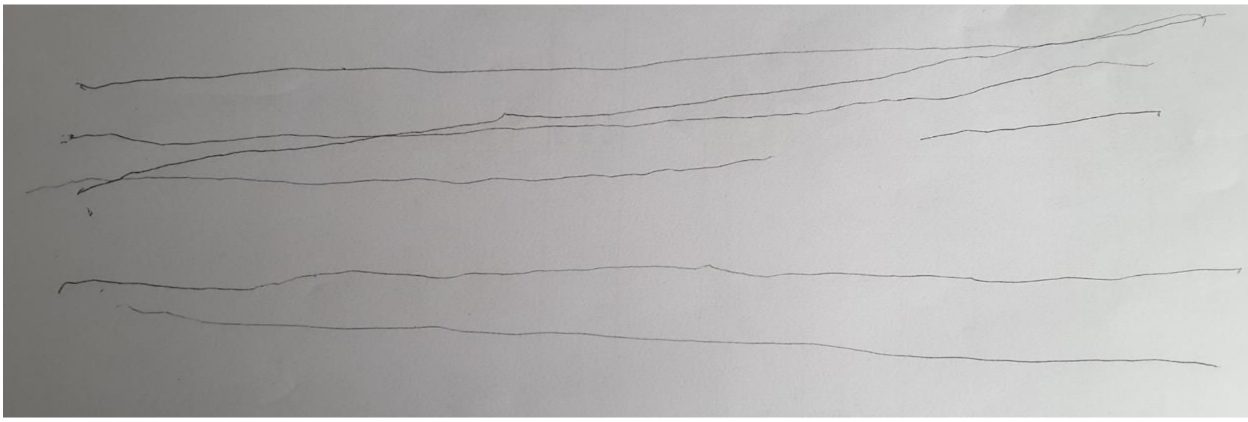


Figure 6.20 c) A redrawn structure of the representative e-commerce category (Subject D4).
Figure 6.20 Examples of redrawn structures by blind participants D1 and D4.

- two of the blind participants (participants with IDs: D2 and D3) redrew the presented structures in a way similar to the original presented structures (cf. figure 6.21 and 6.22). Comparing the presented structures with the redrawn images presented in figures 6.21 and 6.22 indicates an ability of recognizing a structure as a set of distinct rectangular blocks of vibrations, because the redrawn shapes are set of distinct rectangles. In addition, the number of drawn blocks is nearly equal to the number of blocks in the original structures.

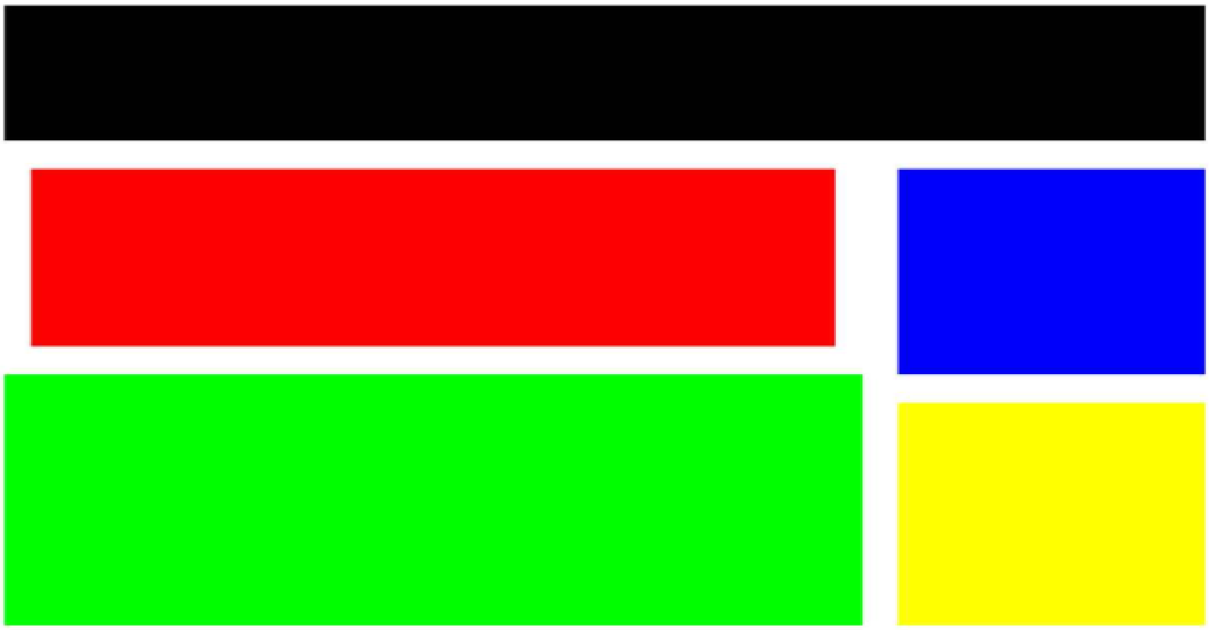


Figure 6.21 a) The original structure of the representative web page of the news category.

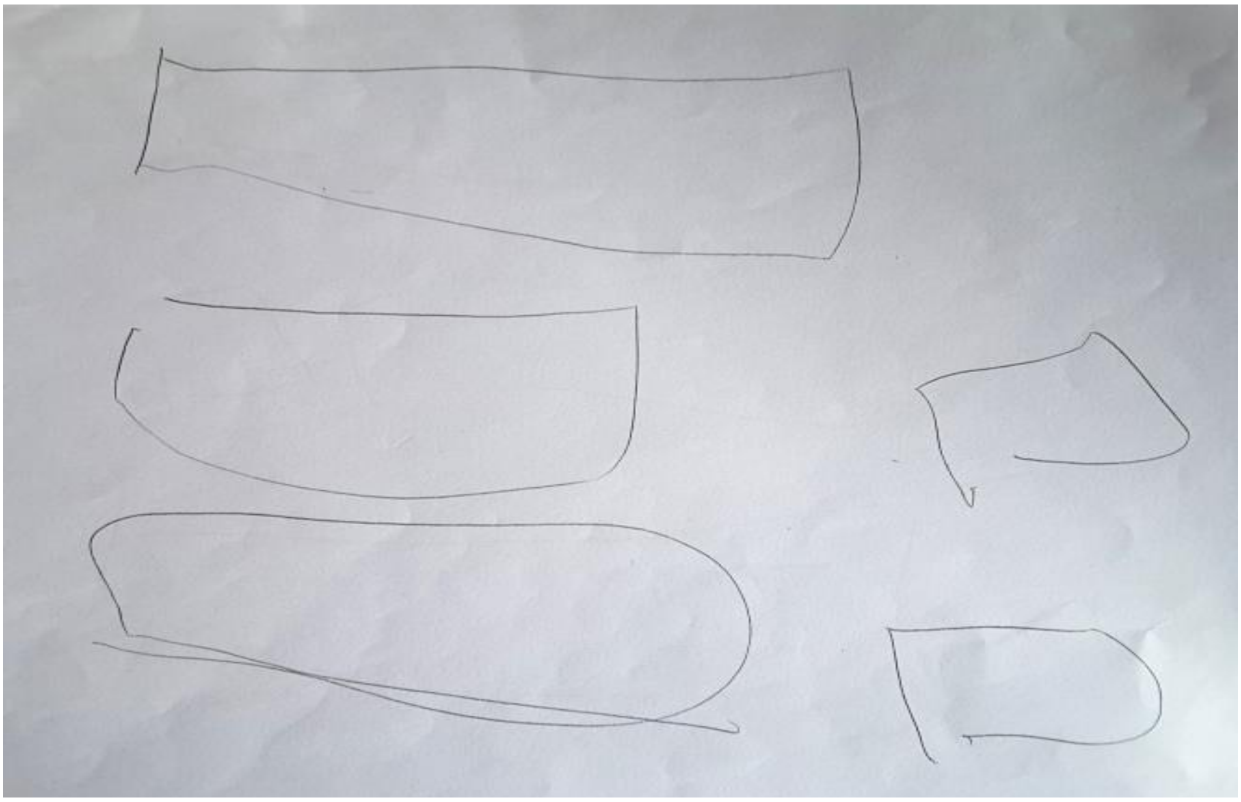


Figure 6.21 b) A redrawn structure of the representative news category (Subject D2).

Figure 6.21 An example of redrawn structures by blind participant D2.

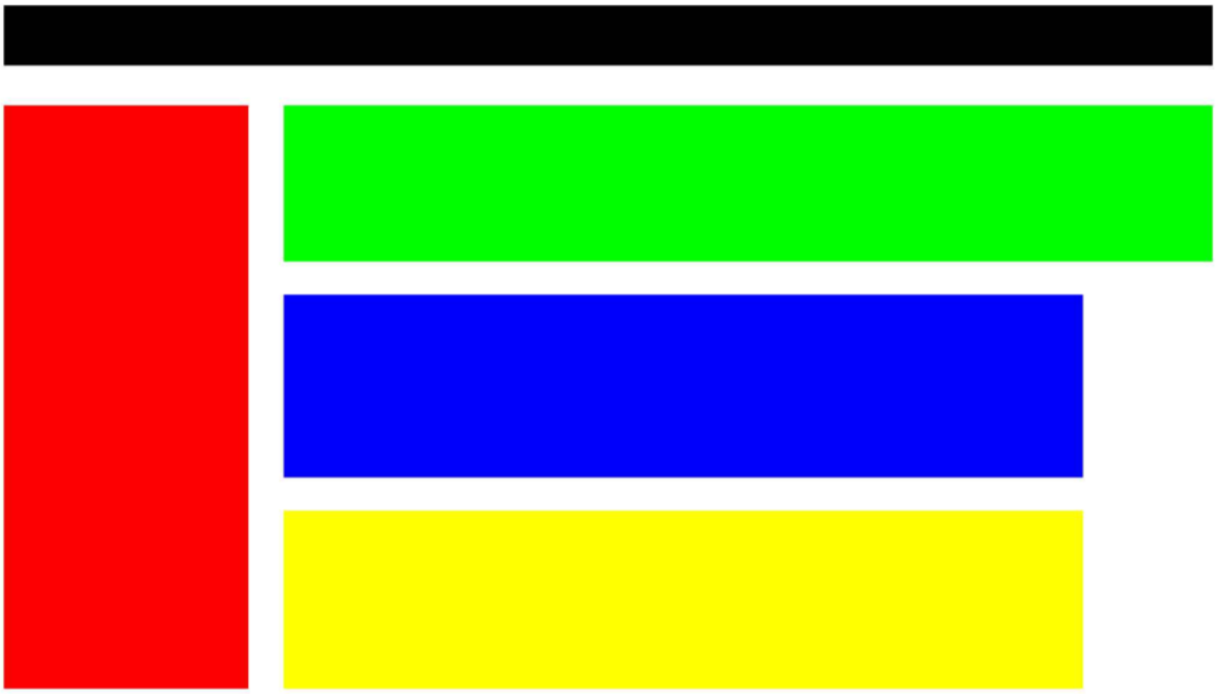


Figure 6.22 a) The original structure of the representative web page of the touristic category.

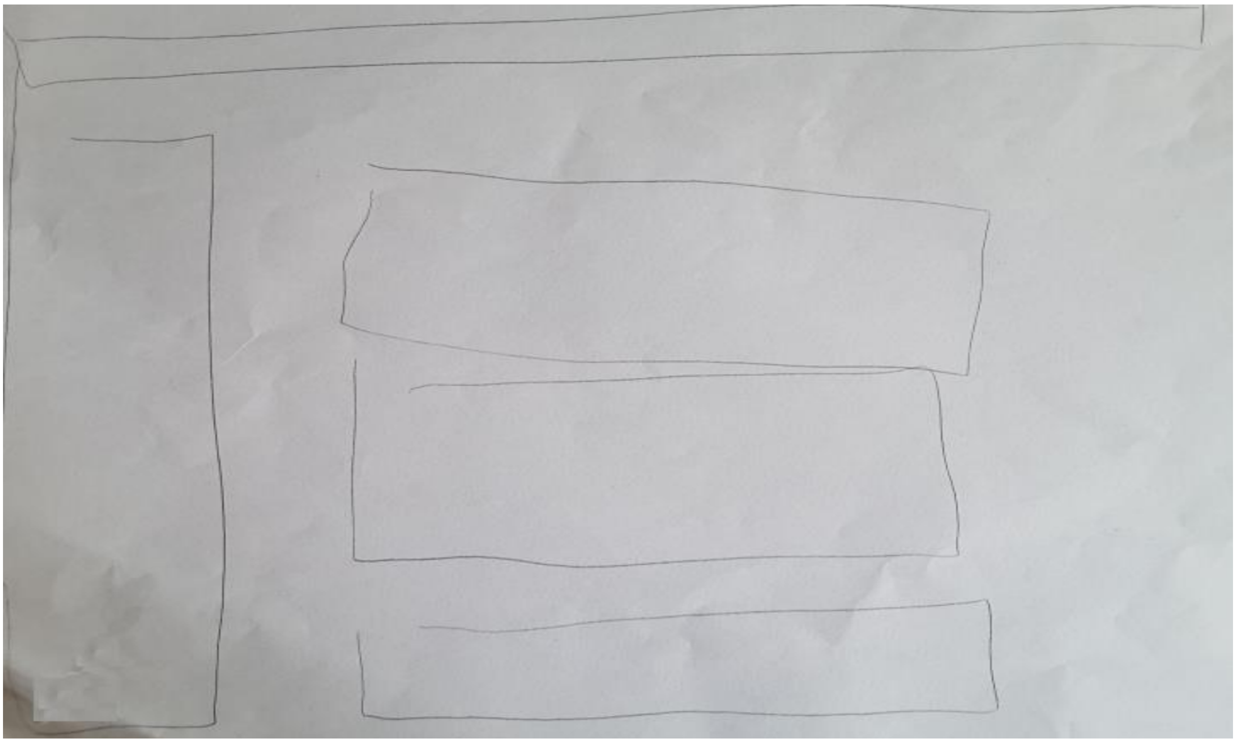


Figure 6.22 b) A redrawn structure of the representative news category (Subject D3).

Figure 6.22 Examples of redrawn structures by blind participant D3.

- Table 6.11 presents for each blind participant some additional information about number of redrawn blocks that match the blocks exist in the original structures.

Table 6.11 Numbers of matching blocks drawn by the blind participants.

Subject id	N° of blocks / First structure (5 blocks)	N° of blocks / Second structure (5 blocks)	Total
D1	0	0	0
D2	4	5	9
D3	5	4	9
D4	0	0	0
D5	0	0	0
Total	**9**	**9**	**18**

- By analyzing the shapes redrawn by participants D2 and D3, the following could be indicated:
  - an ability of distinguishing sizes of shapes, because the degree of scaling between redrawn shapes is nearly equal to the degree of scaling between original shapes.
  - an ability of distinguishing the spatial relationships, because relations of directions (vertical order, left to, right to, etc.) between redrawn shapes is nearly equal to relations of directions between original shapes.

- in what concerns the sighted participants:
  - only one of the 5 sighted participants (subject with ID: V3) redrew the presented structures as horizontal and vertical lines (cf. figure 6.23).

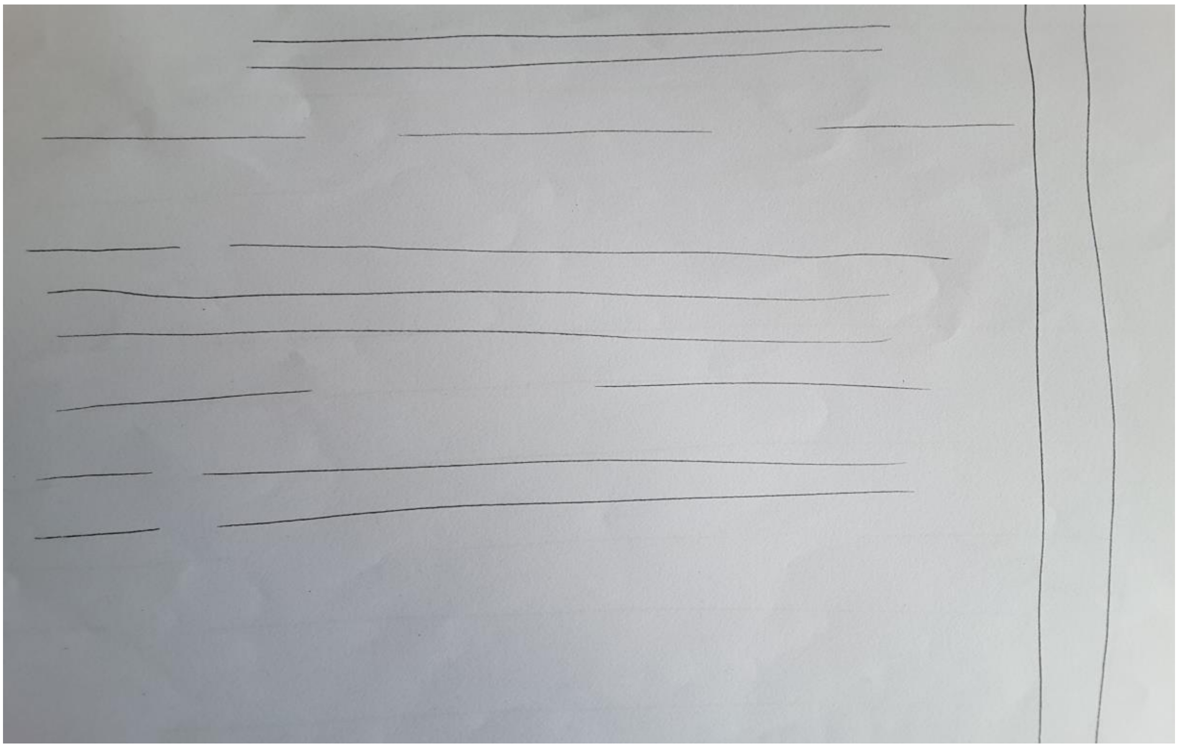


Figure 6.23 A redrawn structure of the representative web page of the news category (Subject V3).

- 4 sighted participants redrew the presented structures as a set of rectangular blocks.
- some of sighted participants redrew structures with more than 5 rectangular blocks (6 or 7 or 8 shapes, cf. figure 6.24);

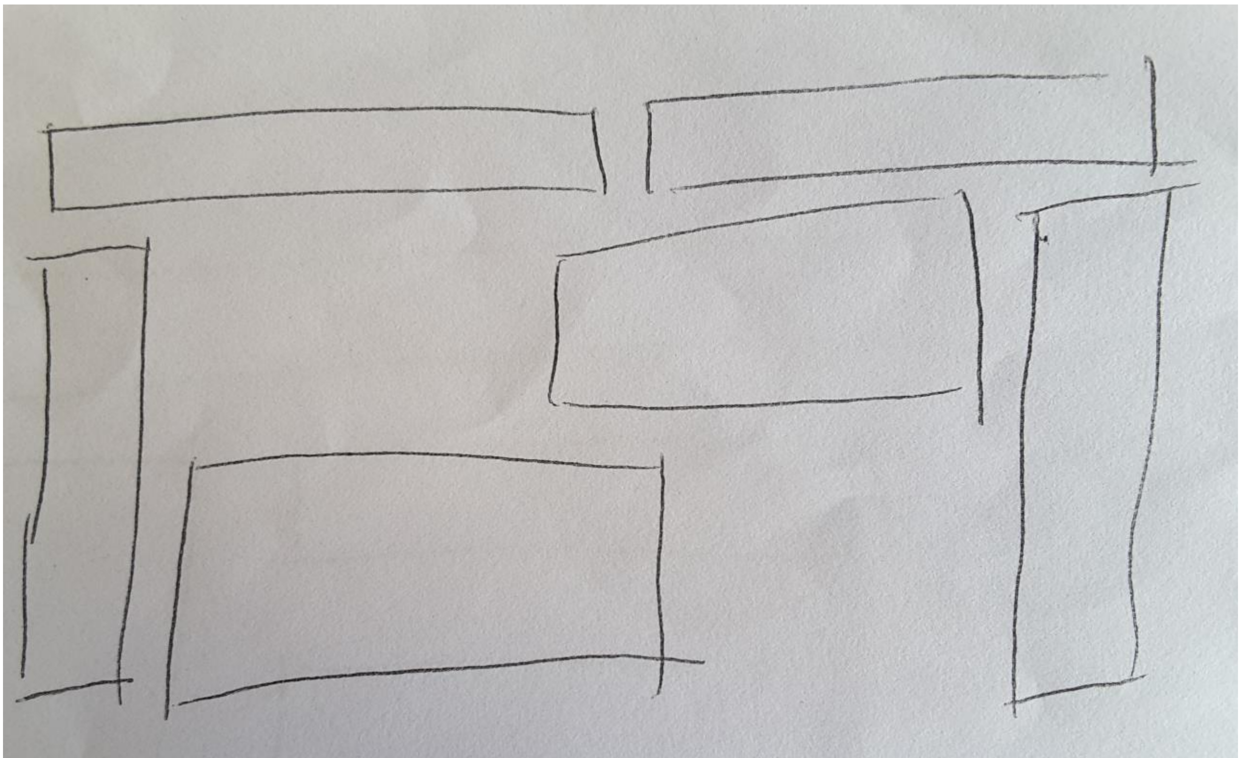


Figure 6.24 A redrawn structure of the representative web page of the news category (Subject V1).

- to evaluate the accuracy percentage of redrawing for the blind and sighted participants, the redrawn shapes have been presented to three persons, two of them are expert in computer human interaction. Each expert person assigned a mark for each redrawn structure. The marks are between 0 and 100. 0 means that the redrawn structure does not match the original structure. 100 means that the redrawn structure matches exactly the original structure. The following features have been evaluated while assigning the marks for each redrawn structure:
    - number of redrawn blocks;
    - spatial relations between redrawn blocks;
    - size of redrawn blocks;

  After assigning a mark (0-100) for each redrawn structure, the mean marks for all participants have calculated. Table 6.12 presents some details about the assigned marks for each sighted and blind participant.

Table 6.12 Marks for the redrawing task.

Subject id	Mark/100	Mean Mark/100
D1	19.2	43.7
D2	72.5	
D3	83.3	
D4	25.0	
D5	18.3	
V1	69.2	50.3
V2	50.0	
V3	18.3	
V4	50.0	
V5	64.2	

- the mean mark of redrawing the navigated structures is 50.3% for the sighted participants and 43.7% for the blind participants. The sighted participants are able to redraw the navigated structures in a way better than the blind participants. This remarkable difference might be due to the way by which the blind and the sighted persons usually navigate the web. The blind persons usually navigate the web in a linear way; for this reason, the majority of blind participants redrew the navigated vibrated structures as vertical and horizontal lines. By the way, the sighted persons navigate the web in a non-linear way;

for this reason, the majority of sighted participants redrew the navigated vibrated structures as rectangular shapes.

- the mean mark of redrawing the navigated structures have been calculated for each web page category (touristic, news, and e-commerce). The mean mark of redrawing the news structures is 54.3%, for the touristic structures is 49.3%, and for the e-commerce structures is 39.3%. It is noticeable that the mean mark of redrawing the e-commerce structures is less than the accuracy percentages of redrawing other structures (touristic and news).

In order to study if there is a correlation between the performance in the first task (recognition the similarity/dissimilarity of two navigated structures) and the performance in the second task (redrawing the navigated structures), the accuracy percentage and the mean marks of the two tasks have been compared for all the participants (cf. figure 6.25 and figure 6.26). The values presented in figure 6.25 have been extracted from tables 6.6, 6.7, and 6.12.

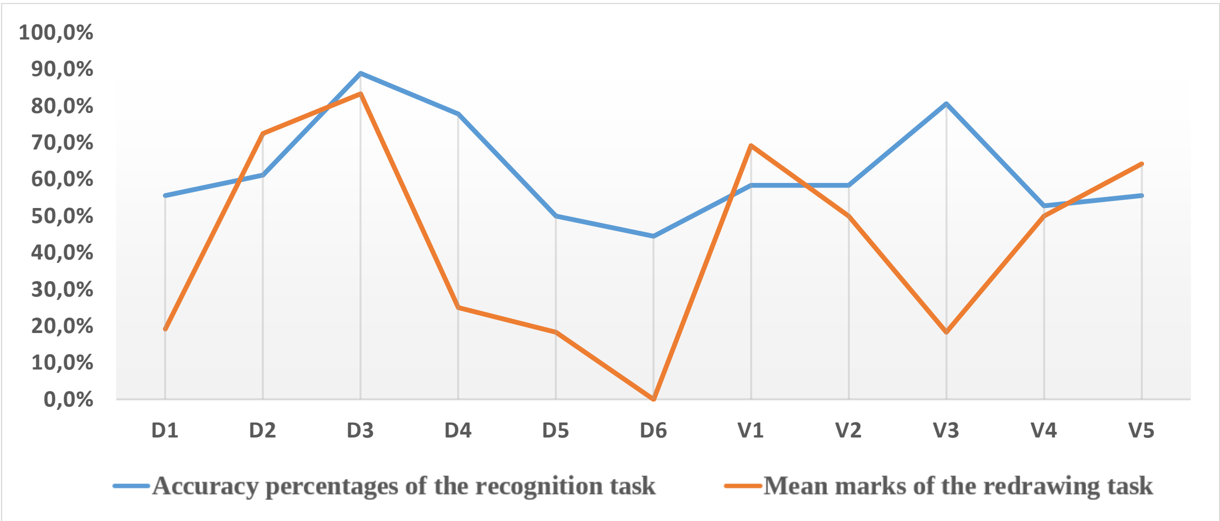


Figure 6.25 Accuracy percentages and the mean marks of the recognition and redrawing tasks for the blind and sighted subjects.

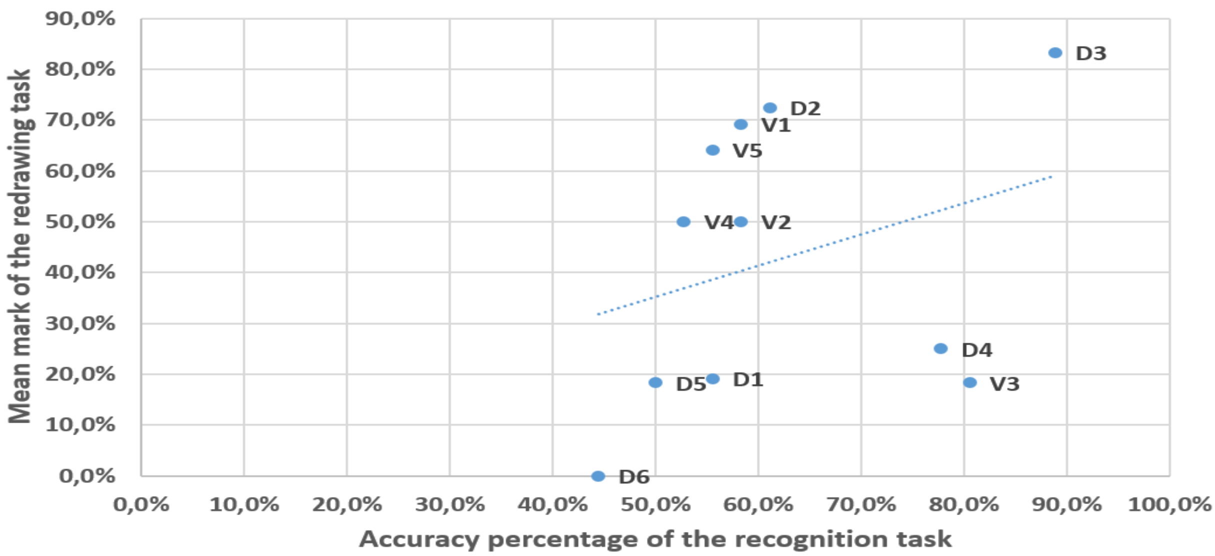


Figure 6.26 Accuracy percentages and the means marks of the recognition and redrawing tasks for the blind and sighted subjects.

The diagrams presented in figures 6.25 and 6.26 view that there is a correlation between the two tasks for some participants such D3 and V2. For other users, there is not a correlation between the two tasks such as the participants V3 and D4.

Evaluating the correlation depending on the accuracy percentages does not take in consideration the ranking of the accuracy percentages. So, in order to compare more precisely the correlation between the two tasks, the accuracy percentages have been ranked for all the participants as presented in table 6.13.

Table 6.13 Ranking of accuracy percentages and mean marks for the recognition and redrawing tasks.

Subject ID	Accuracy percentages of the recognition task	Mean marks of the redrawing task	Ranking of accuracy percentages of the recognition task	Ranking of mean marks of the redrawing task
D1	55.6%	19.2%	6	7
D2	61.1%	72.5%	4	2
D3	88.9%	83.3%	1	1
D4	77.8%	25.0%	3	6
D5	50.0%	18.3%	8	8
D6	44.4%	0.0%	9	9
V1	58.3%	69.2%	5	3
V2	58.3%	50.0%	5	5
V3	80.6%	18.3%	2	8
V4	52.8%	50.0%	7	5
V5	55.6%	64.2%	6	4

Figure 6.27 presents the correlation diagram for the ranked values of accuracy percentages and mean marks of the recognition and redrawing tasks.

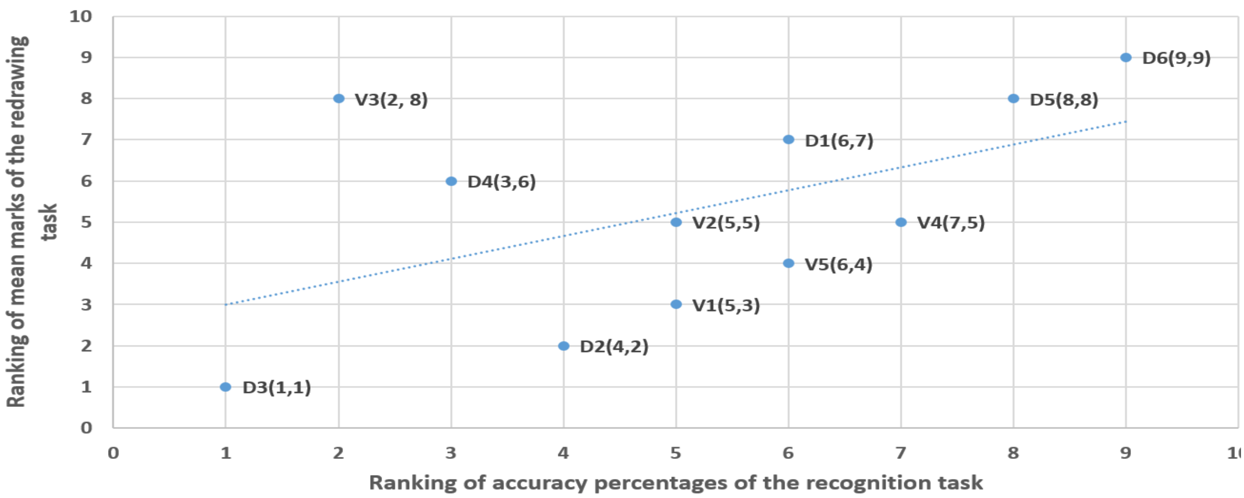


Figure 6.27 Ranking of accuracy percentages of the recognition task versus ranking of mean marks of redrawing task for the blind and sighted subjects.

It is noticeable in figure 6.27 that there is a correlation between the performance in the recognition task and the performance in the redrawing task for the majority of blind and sighted participants. For the participants V3 and D4, there are uncorrelated relations between the performance in the recognition task and the performance in the redrawing task. The total correlation coefficient (a value in the range [-1,1]) for all the participants is 0.523. The correlation coefficient for all the participants except V3 and D4 is 0.89. Assuming that V3 and D4 can be rejected from the study, the correlation coefficient 0.89 means that there is a significant positive correlation for the majority of participants between the performance in the recognition task and the performance in the redrawing task. This positive correlation indicates that the more the person is able to recognize a spatial structure, the more the person is able to redraw the navigated structure.

6.6 Analysis the strategies of navigation

Participants have been filmed in order to analyze and understand more their navigation strategies. Depending on the direction of the navigation, there were about 12 navigation strategies (NS) (cf. figure 6.28).

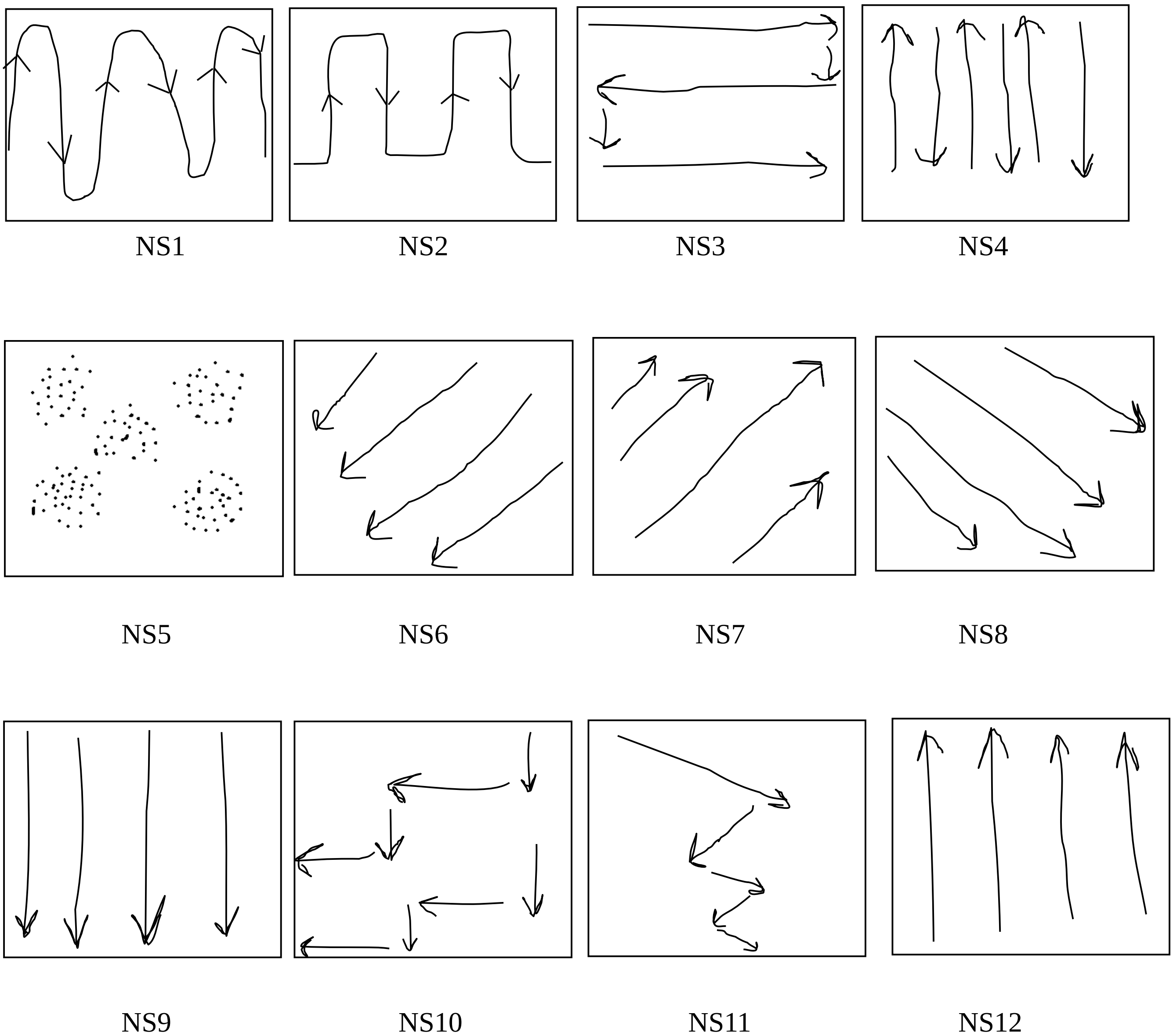


Figure 6.28 Navigation strategies of blind and sighted participants (the symbol NS means navigation strategy.

Figure 6.29 presents an example of applying the navigation strategy NS3 on the representative web page of touristic category.

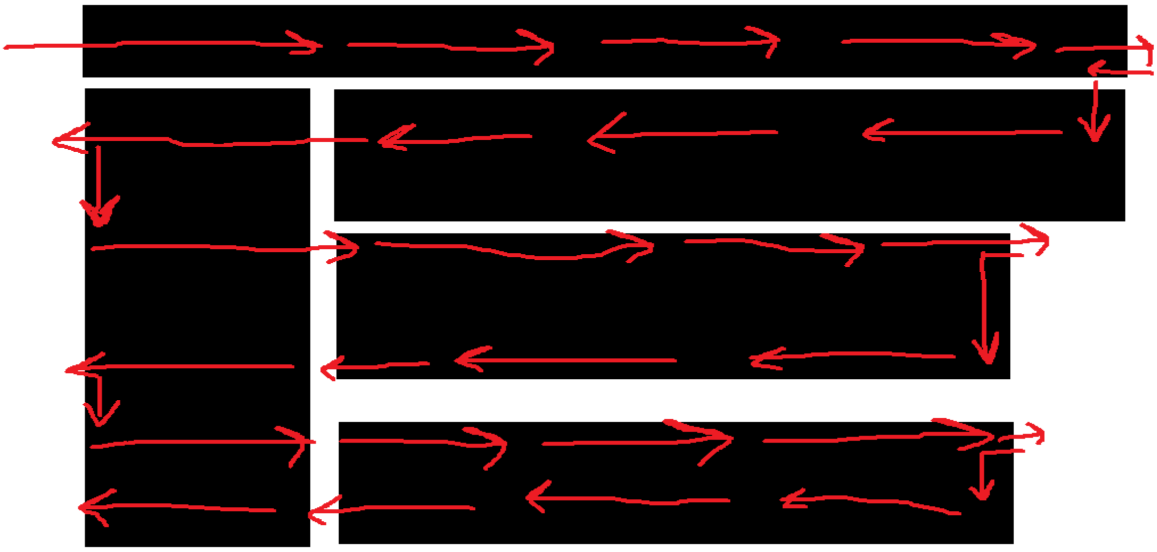


Figure 6.29 Applying the navigation strategy NS3 on the representative web page of touristic category.

It was noticeable during analyzing the videos the following:

- the majority of participants start navigate the tablets from the left side to the right side; this might be due to the cultural habits related to the writing and reading direction for each language. For example, for the languages that are written and read from right to left, the persons will navigate the tablets from right to left.
- the majority of the participants use at least two navigation strategies to navigate the presented structures. Here, it could be differentiated between two types of navigation strategies: micro navigation strategies such the 12 NS presented in figure 6.28, and global navigation strategies that consist of many micro NS.
- the micro navigation strategies NS3 and NS4 are the most used of the majority of participants; these two micro strategies represent the horizontal and vertical navigation methods.
- It was noticeable that there were remarkable differences between the participants in the time and the speed of using each micro strategy.
- table 6.14 presents the navigation strategies chosen by each participant.

Table 6.14 Navigation strategies chosen by each participant.

Subject ID	Chosen navigation strategies
D1	NS1, NS2, NS3, NS4, NS5, NS12
D2	NS3, NS4, NS12
D3	NS1, NS3, NS4, NS12
D4	NS10, NS3, NS4, NS12
D5	NS3, NS9, NS8
D6	NS3, NS4, NS9, NS8
V1	NS11, NS3, NS4, NS6, NS7, NS12
V2	NS3, NS4, NS12
V3	NS3, NS4
V4	NS3, NS4, NS12
V5	NS3, NS4

In table 6.14, it is noticeable that the participants V3, V4, and V5 use nearly the same micro strategies, despite they get different accuracy rates and mean marks for the recognition and the redrawing tasks.

Applying nearly the same micro strategies by the participants and obtaining different accuracy rates in different tasks indicate that the type of chosen navigation strategy is not the only parameter that causes well or bad accuracy rates. There might be many other parameters that causes the success in the achieved tasks, such:

- the time and the speed of applying the global and the micro NS,
- the successive of micro strategies in certain global strategy,
- on which parts of the tablet the NS has been applied,
- how many times the global and the micro NS have been applied,
- other internal parameters related to the participant, such the experience in dealing with tactile technologies, and the ability to learn and to deal with new technique and technologies.

6.7 Conclusion of Chapter 6

In this chapter, the performance of sighted and blind participants in recognizing structures of web pages and redrawing navigated structures has been evaluated. To summarize the obtained results:

- 62.1% is the total accuracy percentage of the participants in recognition web pages structures;
- there is not a significant difference in recognizing the structures between the blind and the sighted participants;
- concerning the sighted participants, there is not a significant difference in recognizing the structures by changing the amplitude values; while, for the blind participants, there is a little enhancement in recognizing the structures by changing the amplitude values;
- the more the blind users are familiar with touch-screen techniques, the more they are able to use the designed system;
- the accuracy percentage for comparing the dissimilar structures is higher than the accuracy percentage in comparing the similar structures;
- the participant answers that two structures are similar only if he/she is absolutely sure of his/her answer; but when the participant has a doubt about the correct answer, he/she chooses that the two structures are dissimilar;
- the majority of blind participants did not perceive the structure as a set of separated (disconnected, distinct, distinguished) rectangular blocks of vibrations, but they perceived the structure as a series of sequences of continuous vibrations organized linearly either horizontally or vertically;
- some blind participants and the majority of sighted participants presented an ability of distinguishing sizes of shapes, and an ability of distinguishing the spatial relationships between original shapes;
- sighted participants are able to redraw the navigated structures in a way better than the blind participants;
- there is a significant positive correlation for the majority of participants between the performance in the recognition task and the performance in the redrawing task;
- the more the person is able to recognize a spatial structure, the more the person is able to redraw the navigated structure;
- about 12 navigation strategy have been applied during the experiment;
- participants start navigate the presented structures from the left side to the right side;
- the majority of the participants use at least two navigation strategies to navigate the presented structures;
- the horizontal and vertical navigation strategies (cf. NS3 and NS4 in figure 6.28) are the most used of the majority of participants;

Training the participants on the designed system for a sufficient period enhances their performance and their ability to recognize the navigated structures. Training the blind participants to navigate the Web using touch-screen devices enhances their ability to deal with the designed system. This experiment has been conducted with a fixed frequency value equals 304.6875 Hz; combining other frequency values with the chosen amplitude values might enhance the performance of the participants. Analyzing many parameters concerning the global and the micro navigation strategies such the time, the speed, and their successive might result new observations. These observations could be useful in developing new versions of the designed system.

Conclusion and perspectives

A non-visual interaction approach has been presented in this work. The approach is based on a vibro-tactile modality. It presented a tactile interface that helps to explore the layout of the presented document in a non-visual way. The proposed system converts the visual structures that represent the layout of a web page into vibro-tactile feedbacks.

The work aimed to explore the effects of the tactile modality on the interpretation and perceiving of web pages layouts. To explore these effects, an embedded device has been designed, a web page segmentation algorithm has been suggested, and a series of experiments with blind and sighted participants have been conducted.

The main contributions proposed in this work were:

1. designing a tactile vision sensory substitution system (TVSS) represented by an electronic circuit and an Android program in order to generate low-frequencies vibrations;
2. designing and evaluating an algorithm for segmenting web pages;
3. conducting a series of experiments with blind and sighted participants in order to analyze the effects of the suggested approach on web navigation models and tactics of the participants;
4. modelling an approach that focuses on proving the importance of the vibro-tactile modality to allow better interpretation of the web pages layouts;

The work proved that the vibro-tactile modality supports the visually impaired persons by a way to explore graphical geometrical shapes presented on touch-screen mobile devices. The conducted experiments gave a better understanding of the way by which the persons interpret the web pages. The conducted experiments supported pieces of information about the best parameters of amplitude and frequency values to be used in vibro-tactile interfaces. They gave more understanding about the navigation strategies preferred by the participants.

A basic model of a graphical vibro-tactile language GVTL has been suggested. This model consists of a set of graphical symbols, a set of distances between the graphical symbols, a set of frequencies, a set of amplitudes, and set of vibrations, where each vibration is represented by two values frequency and amplitude.

Depending on the conducted experiments, the following results have been obtained:

- the less the shape has gradient transitions, the more it is recognizable;
- the more the user increases the pressure on the touched surface, the more he/she is interested in the touched graphical element;
- the reference frequency 304.6875Hz and the amplitude 55 have the smallest differential perceptual thresholds;
- changing amplitude values with simple variabilities do not affect on the performance of the participants,
- the performance of sighted and blind participants is nearly equal in discriminating ranges of frequencies and amplitudes;
- there is no significant effect of the age in discriminating ranges of frequencies and amplitudes;
- there is not a noticeable difference in recognizing the structures between the blind and the sighted participants;
- comparing the dissimilar vibrating structures is easier than comparing the vibrating similar structures;
- there is a correlation between the performance in the recognition of structures task and the performance in the redrawing of structures task for the majority of blind and sighted participants;
- the horizontal and vertical navigation strategies are the most used micro strategies;

- there is not a significant difference in recognizing the structures between the blind and the sighted participants;
- the more the blind users are familiar with touch-screen techniques, the more they are able to use the designed system.

This work has been achieved by collaborating with experts of many specializations: electronics, psychology, computer human interaction, and image processing. This collaboration was useful to guarantee best conditions to prepare and to conduct the experiments, and to analyze the results. In addition, it was very useful on the personal side to contact with experts of many specializations, and to explore many new methods of data analysis and results evaluation.

The suggested segmentation algorithm has some drawbacks. Many enhancements could be suggested in order to increase the efficiency of extracting and representing the contents of web pages, such:

- enhancing the suggested algorithm to deal with the contents of tables and lists rather than considering them as single blocks;
- supporting a wide range of similarity features such similarity of color of segments, or semantic similarities between the textual contents of segments;
- supporting some advances web techniques such as AJAX for websites which their contents can be updated frequently;
- the considered distance between two segments is the Euclidean distance between their centroids. The algorithm does not support any another type of distances such minimum and maximum distances between the edges of segments;
- comparing the proposed algorithm with other segmentation algorithms helps more to extract its strength points and its drawbacks.

Conducting more experiments helps in exploring the best combinations for the amplitude and the frequency parameters, and this might enhance the way by which the tactile interfaces are presented. Conducting multi-touch experiments using many actuators might support the participants with more options to explore the presented layouts in more efficient way. Integrating textures with the presented tactile structures (and classifying these textures) might enhance the ability of users to perceive the web pages layouts.

Using thermic actuators provides a temperature feedback to support more semantic feedbacks about the navigated parts on the touch screens. Integrating the temperature feedback with the vibro-tactile feedbacks might enhance the way by which the persons perceive the web pages layouts. Developing the system to be multimodal (vibrotactile, oral, and thermic) might enhance the capacities of users to implement more efficient skimming and scanning strategies.

Analyzing many parameters concerning the global and the micro navigation strategies such the time, the speed, and their successive might result new observations. These observations could be useful in developing new versions of the designed system.

The obtained results about the best parameters and the navigation strategies should be explored more in order to get a deep understanding about the navigation strategies and the other conditions that cause well perceiving of the presented tactile layouts.

Despite some participants apply nearly the same micro strategies to navigate the presented structures, they obtain different accuracy rates in different tasks. This difference indicates that the type of chosen navigation strategy is not the only parameter that causes well or bad accuracy rates. More experiments should be conducted in order to study the parameters that causes the success in the achieved tasks, such:

- the time and the speed of applying the global and the micro navigation strategies;

- the successive of micro strategies in certain global strategy;
- on which parts of the tablet the navigation strategies have been applied;
- how many times the global and the micro navigation strategies have been applied;
- other internal parameters related to the participant, such the experience in dealing with tactile technologies, and the ability to learn and to deal with new technique and technologies.

Training the participants is fundamental to enhance their ability to deal with the designed system, and to make them more familiar with the designed tactile interfaces. Designing a multi-modal system by combining the vibro-tactile modality with the oral modality might enhance the non-visual interactions. All these proposed enhancements should be evaluated by conducting experiments with blind and sighted persons in order to guarantee achieving a "design for all" solution.

This work answered some questions in the vibro-tactile modality domain, but in the same time it posed more future questions, for example:

- what are the real relations between the layout skimming and the content scanning, and how this could be represented in the non-visual navigation when combining multi-modalities such the tactile, the thermic, and the vocal modalities?
- what are the best combinations between the tactile, the thermic, and the vocal modalities to guarantee best and successful navigation strategies?
- what are the conditions that enhance the learning process of the users in dealing with such designed tactile vision substitution system? This includes internal conditions such the personal human capacities, the experience in dealing with these systems, and the affordances proposed by the system to enhance the action-perception coupling. Selecting these conditions allows designing new multimodal computer human interfaces in the perspective of "design for all".

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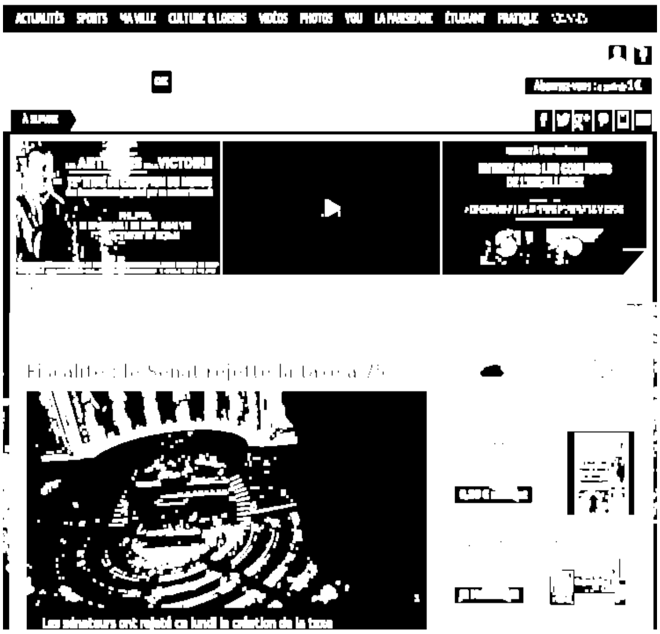
Appendix A

Mathematical morphology and choosing an image processing based segmentation approach

Mathematical morphology is a theory most commonly applied to digital images. This theory is used for analyzing and processing of geometrical structures in the image based on a set of geometrical and topological functions [Serra, 1983]. In mathematical morphology, the most basic operations are erosion and dilation [Serra, 1983]. The basic effect of the erosion operation on a binary image (an image with white and black colors) is to erode away the boundaries of regions. The basic effect of the dilation operation is to enlarge the boundaries of regions. Figure A.1 views an example of applying the erosion and the dilation operations on a binary image. The tool ImageJ (Image Processing and Analysis in Java) [Imagej, 2016] has been used for applying these two operations.

(a) Home page of site www.leparisien.fr

(b) A binary version of image (a)



(c) Erosion on image (b)

(d) Dilation on image (b)

Figure A.1 Erosion and dilation on a binary image captured from the site www.leparisien.fr.

There are many other mathematical morphology operations such [Serra, 1983]:

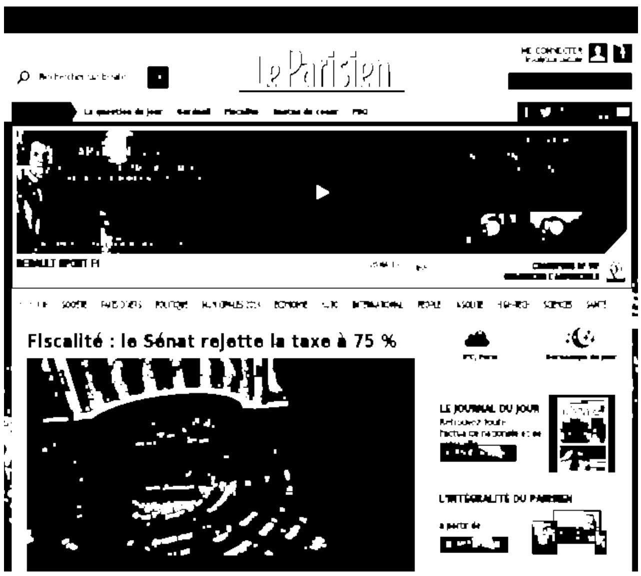
- **opening:** removing some of the bright pixels from the edges of regions, similar to erosion operation;
- **closing:** enlarging the boundaries of bright regions in an image, similar to dilation operation;
- **skeletonization**: extracting a region-based shape feature that represents the general form of an object in an image;
- **filling holes:** filling holes in objects of an image; and
- **edge detection:** finding edges of objects in an image.

All the previous mentioned mathematical morphology operations can be defined in terms of combinations of erosion and dilation by applying set of operators such as intersection and union [Serra, 1983]. Figure A.2 views some examples of applying mathematical morphology operations on a binary image captured from the site www.leparisien.fr.

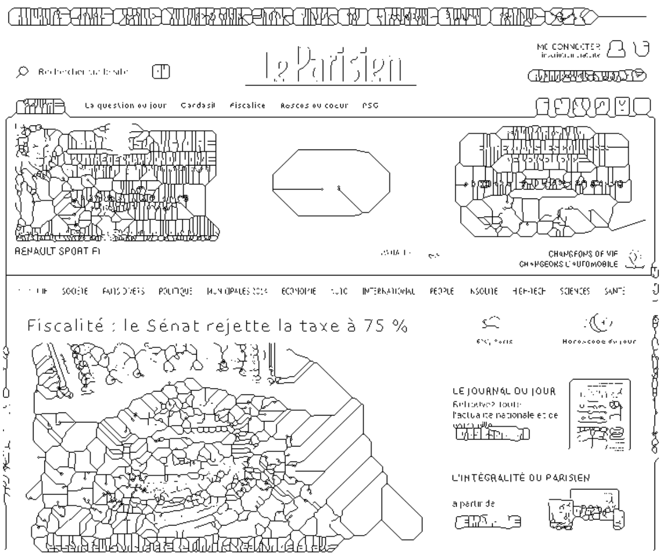
(a) Home page of site www.leparisien.fr

(b) A binary version of image (a)

(c) Opening operation on image (b)

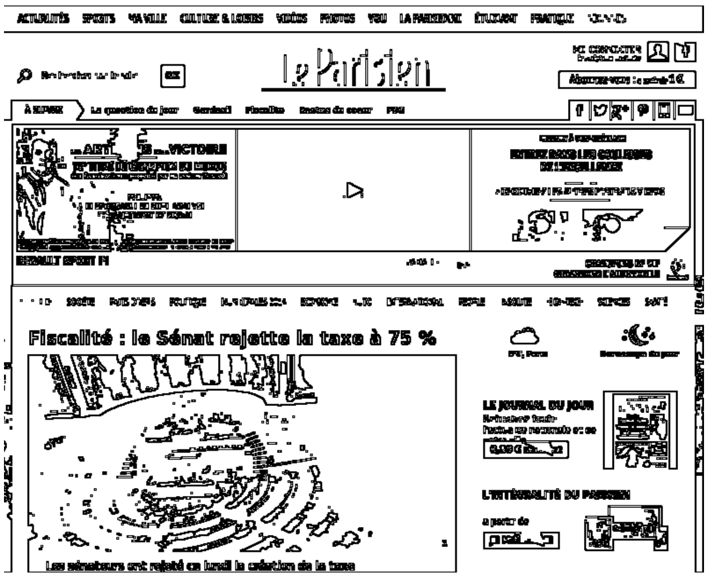


(d) Closing operation on image (b)



(e) Skeletonization operation on image (b)

(f) Filling holes operation on image (b)



(g) Edge detection operation on image (b)

Figure A.2 Mathematical morphology operations on a binary image from www.leparisien.fr.

Appendix B

Manual and automatic web page segmentation comparison

The suggested algorithm presented in chapter 5 has been run with 8 web pages (2 pages from www.cdiscount.com, 2 pages from www.photobox.com, 2 pages from www.rueducommerce.fr, 1 page from www.w3schools.com, and 1 page from www.leparisien.fr). The algorithm segmented each web page into 3, 4, 5, and 6 zones. The comparison between manual and automatic segmentation is presented in tables B.1 and B.2.

Table B.1 Fully-matched criterion of manual and automatic segmentation.

	Page1	Page2	Page3	Page4	Page5	Page6	Page7	Page8	Total
3 Zones	1	0	0	6	3	0	9	1	20
4 Zones	1	5	4	3	3	0	3	2	**21**
5 Zones	4	4	1	4	3	0	0	2	18
6 Zones	4	1	2	2	4	1	0	1	15
Total	10	10	7	15	13	1	12	6	74

Table B.2 Partially-matched criterion of manual and automatic segmentation.

	Page1	Page2	Page3	Page4	Page5	Page6	Page7	Page8	Total
3 Zones	8	10	8	9	9	2	12	6	**64**
4 Zones	7	5	7	8	10	4	13	7	61
5 Zones	8	6	6	5	7	6	8	9	55
6 Zones	6	4	7	5	8	5	10	3	48
Total	29	25	28	27	34	17	43	25	228

Table B.1 illustrates matching results based on a fully-matched criterion. Depending on this criterion, two segmentation results (manually and automatically) can be considered matched if the results are 100% identical without any difference. It is concluded from table B.1 that pages segmented automatically and manually into 4 zones are more matched than pages segmented into other numbers of zones. The percentage of identical matching depending on the fully-matched criterion is 15.42% (74 identical matched results of 480 segmented copies). Table B.2 illustrates matching results based on partially-matched criterion. Depending on this criterion, two segmentation results can be considered matched if at least 50% of the results are identical. It is concluded from table B.2 that pages segmented automatically and manually into 3 zones are more matched than pages segmented into other numbers of zones. The matching percentage depending on the partially-matched criterion is 47.5% (228 matched results of 480 segmented copies).

Figures B.1 and B.2 illustrate matching results as percentages of the manual segmented pages based on the two proposed criteria. The horizontal axe indicates the segmented pages and the number of zones, and the vertical axe indicates percentage of matching for automatic segmented pages with manual segmented pages.

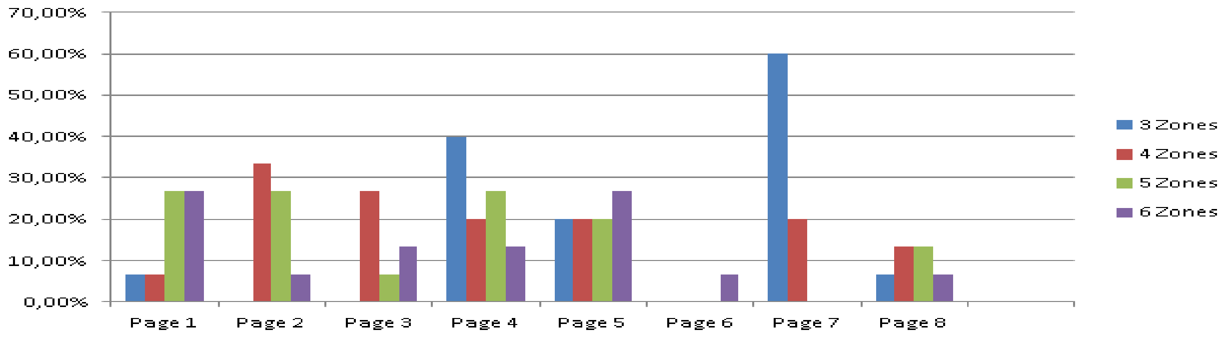


Figure B.1 Percentage of fully-matched criterion based matching results of manual and automatic segmentation.

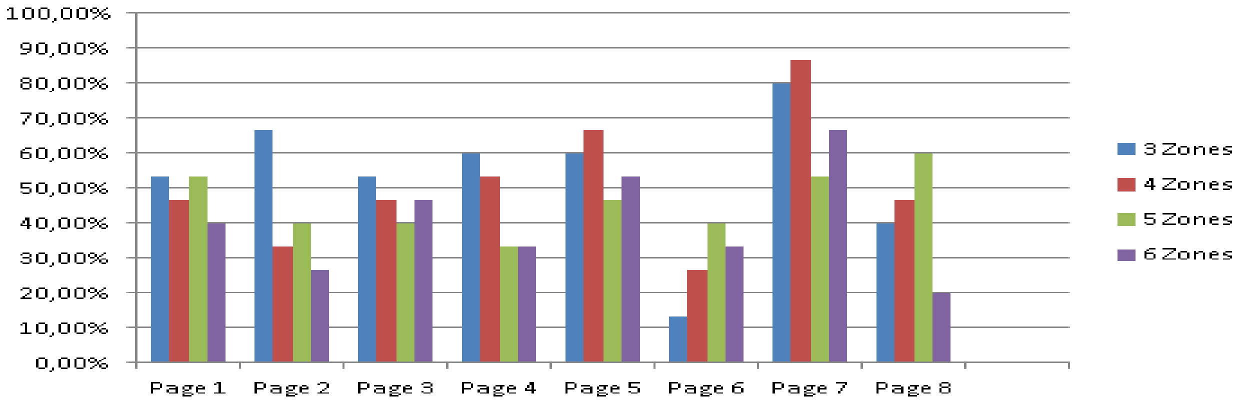


Figure B.2 Percentage of partially-matched criterion based matching results of manual and automatic segmentation.

The percentages have been calculated via dividing the number of matched results by the number of users (15). For example, in figure B.1, for the page number 7, the percentage of matching the automatic 3-zones segmentation with the manual segmentation is 60% (9 matching /15 users).

Appendix C
List of sites used to construct ART-ADN corpus

	Touristic	E-commerce	News
1	www.nicetourisme.com/	www.accorhotels.com	http://lci.tf1.fr/
2	www.biarritz.fr/	www.achatdesign.com	http://haitienmarche.com/
3	www.parisinfo.com/	www.adamence.com	http://hebdo.ahram.org.eg/
4	www.bordeaux-tourisme.com/	www.airfrance.fr	http://lepays.bf/
5	www.allemagne-tourisme.com/	www.alicesgarden.fr	http://lnt.ma/
6	www.visitbritain.fr/	www.allobebe.fr	http://news.google.fr/
7	www.visitportugal.com/	www.Allopneus.com	http://permanent.nouvelobs.com/
8	http://www.viamichelin.fr/	www.alloresto.fr	http://portail.journalmtl.com/
9	http://regionfrance.com/	www.alltricks.fr	http://www.20minutes.fr/
10	http://www.tourisme.fr/	www.annikids.com	http://www.africatime.com/
11	http://www.france-voyage.com/	www.aramisauto.com	http://www.afriqueindex.com/
12	http://www.provenceweb.fr/	www.asdiscount.com	http://www.aip.ci/
13	http://www.aixenprovencetourism.com/	www.bebe-au-naturel.com	http://www.alterpresse.org/
14	http://www.francetourisme.fr/	www.berceaumagique.com	http://www.bienpublic.com/
15	http://www.ot-montpellier.fr/	www.bestwestern.fr	http://www.commentcamarche.net/
16	http://www.destinationsuddefrance.com/	www.bien-et-bio.com	http://www.courrierint.com/
17	http://www.tourisme-menton.fr/	www.bienmanger.com	http://www.courrierinternational.com/
18	http://www.toulouse-tourisme.com/	www.bonoboplanet.com	http://www.directmatin.fr/
19	http://atout-france.fr/	www.breal.net	http://www.dna.fr/
20	http://www.meribel.net/	www.cache-cache.fr	http://www.elmoudjahid.com/
21	http://www.tourisme-lot.com/fr	www.cdiscount.com	http://www.elwatan.com/
22	http://www.tourisme-handicaps.org/	www.cocooncenter.com	http://www.estrepublicain.fr/
23	http://www.avoriaz.com/	www.comptoirdescotonniers.com	http://www.europe1.fr/
24	http://www.valthorens.com/	www.conrad.fr	http://www.fdlm.org/
25	http://www.legrandbornand.com/	www.crucial.fr	http://www.france-amerique.com/
26	http://www.franche-comte.org/	www.cuisineaddict.com	http://www.francesoir.fr/
27	http://www.hotels-roissy-tourisme.com/	www.debonix.fr	http://www.fratmat.info/
28	http://www.ardennes.com/	www.delamaison.fr	http://www.horizons-dz.com/
29	http://www.parisinfo.com/	www.destockoutils.fr	http://www.huffingtonpost.fr/
30	http://www.visitparisregion.com/	www.destock-sport-et-mode.com	http://www.humanite.fr/
31	http://www.gites-de-france.com/	www.easyflyer.fr	http://www.journaldunet.com/
32	http://www.peisey-vallandry.com/	www.easylunettes.fr	http://www.la-croix.com/
33	http://www.letouquet.com/	www.easyparapharmacie.com	http://www.ladepeche.fr/
34	http://www.courchevel.com/	www.expertissim.com	http://www.laliberte.ch/
35	http://www.avignon-tourisme.com/	www.familytrip.fr	http://www.lalibre.be/
36	http://www.amiens-tourisme.com/	www.flashrc.com	http://www.lamontagne.fr/
37	http://www.lesgets.com/	www.franceloisirs.com	http://www.lanouvellegazette.be/
38	http://www.otstrasbourg.fr/fr/	www.fruitrouge.com	http://www.lanouvellerepublique.fr/
39	http://www.belle-ile.com/	www.galerieslafayette.com	http://www.lapresse.ca/
40	http://www.lac-annecy.com/	www.gefradis.fr	http://www.laprovence.com/
41	http://www.tours-tourisme.fr/	www.glisshop.com	http://www.latribune.fr/
42	http://www.larosiere.net/	www.graphic-reseau.com	http://www.lavoixdunord.fr/
43	http://www.tourisme-creuse.com/	www.greenweez.com	http://www.leberry.fr/accueil.html
44	http://www.pau-pyrenees.com/	www.grosbill.com	http://www.ledauphine.com/
45	http://www.dordogne-perigord-tourisme.fr/	www.idtgv.com	http://www.lefigaro.fr/

46	http://www.cabourg.net/	www.ixtem-moto.com	http://www.lejdc.fr/accueil.html
47	http://saint-etiennetourisme.com/	www.jardideco.fr	http://www.lejsl.com/
48	http://www.tourisme-metz.com/fr/accueil.html	www.ldlc.com	http://www.lematin.ma/
49	http://www.tahiti-tourisme.fr/	www.lemoncurve.com	http://www.lemauricien.com/
50	http://www.sixtferacheval.com/	www.lyreco.fr	http://www.lemonde.fr/
51	http://www.perpignantourisme.com/	www.mapetitemercerie.fr	http://www.lenouveaureveil.com/
52	http://www.uzes-tourisme.com/	www.mathon.fr	http://www.leparisien.fr/
53	http://www.bienvenue-a-la-ferme.com/	www.melijoe.com	http://www.lepatriote.net/
54	http://www.collioure.com/	www.mencorner.com	http://www.lepoint.fr/
55	http://www.tourisme-conques.fr/	www.meseo.fr	http://www.lepopulaire.fr/accueil.html
56	http://www.provenceguide.com/	www.missnumerique.com	http://www.leprogres.fr/
57	http://www.nantes-tourisme.com/	www.mister-auto.com	http://www.lequipe.fr/
58	http://www.grenoble-tourisme.com/fr/	www.mode-in-motion.com	http://www.lesclesjunior.com/
59	http://www.tourisme-cahors.fr/	www.mondebio.com	http://www.lesechos.fr/
60	http://www.nancy-tourisme.fr/	www.monechelle.fr	http://www.lesoftonline.net/
61	http://www.ot-colmar.fr/fr/	www.mon-marche.fr/	http://www.lesoir.be/
62	http://www.saint-emilion-tourisme.com/	www.morgandetoi.com	http://www.letelegramme.com/
63	http://www.auvergne-tourisme.info/	www.motoblouz.com	http://www.letemps.ch/
64	http://www.ariege.com/	www.mypiscine.com	http://www.lexpansion.com/
65	http://www.argeles-sur-mer-tourisme.com/	www.nice.aeroport.fr	http://www.lexpress.ch
66	http://www.rouentourisme.com/	www.notrefamille.com	http://www.lexpress.fr/
67	http://www.vallee-dordogne-rocamadour.com/	www.officedepot.fr	http://www.lexpress.mu/
68	http://www.berryprovince.com/	www.outy-store.fr	http://www.lexpressmada.com/
69	http://www.tourisme-nord.fr/	www.pixmania.fr	http://www.liberation.com/
70	http://www.chamrousse.com/	www.placedestendances.com	http://www.linternaute.com/
71	http://www.normandie-tourisme.fr/	www.polytrans.fr	http://www.lorientlejour.com/
72	http://www.bonjour-tunisie.com/	www.princessetamtam.com	http://www.lyoncapitale.fr/
73	http://www.larochelle-tourisme.com/	www.raja.fr	http://www.lyonne-republicaine.fr/
74	http://www.ot-cassis.com/	www.ruedeshommes.com	http://www.madagascar-tribune.com/
75	http://www.francevelotourisme.com/	www.rueducommerce.fr	http://www.mediapart.fr/
76	http://www.angersloiretourisme.com/fr	www.rugbyshop.com	http://www.metronews.fr/
77	http://www.veilleinfotourisme.fr/	www.salaun-holidays.com	http://www.midilibre.fr/
78	http://www.jura-tourism.com/	www.showroomprive.com	http://www.midi-madagasikara.mg/
79	http://www.loches-tourainecotesud.com/	www.skiset.com	http://www.monde-diplomatique.fr/
80	http://office.tourisme-richelieu.fr/	www.sonovente.com	http://www.nicematin.fr/
81	http://www.albi-tourisme.fr/	www.spartoo.com	http://www.osservatoreromano.va/fr
82	http://www.lacharente.com/	www.splendia.com	http://www.ouest-france.fr/
83	http://www.ot-ceret.fr/	www.sport-decouverte.com	http://www.paris-normandie.fr/
84	http://www.lilletourism.com/	www.t-a-o.com	http://www.republicain-lorrain.fr/
85	http://www.somme-tourisme.com/	www.tati.fr	http://www.rtl.fr/
86	http://www.tourisme-pyreneesorientales.com/	www.tennisachat.com	http://www.rue89.com/
87	http://www.lourdes-infotourisme.com/	www.tikamoon.fr	http://www.sudonline.sn/
88	http://www.tourisme93.com/	www.tompress.com	http://www.sudouest.com/
89	http://www.villarddelans.com/	www.tuto.com	http://www.walf-groupe.com/
90	http://www.ville-vichy.fr/	www.ventealapropriete.com	http://www.afp.com/
91	http://tourisme.yvelines.fr/	www.vente-du-diable.com	http://www.regards.fr/
92	http://www.tourisme-midi-pyrenees.com/	www.vente-privee.com	http://www.canadafrancais.com/
93	http://www.france-pittoresque.com/	www.voltex.fr	http://www.lebulletinregional.com/
94	http://www.valencetourisme.com/	www.voyages-sncf.com	http://www.ledevoir.com/

95	http://www.offices-de-tourisme-de-france.org/	www.wanimo.com	http://www.lagauche.com/
96	http://www.saint-raphael.com/fr/	www.weekendesk.fr	http://fr.canoe.ca/
97	http://www.tourisme-gers.com/	www.wengo.fr	http://www.telequebec.tv/
98	http://www.saintesmaries.com/fr/	www.woodbrass.com	http://www.cameroon-info.net/
99	http://www.quotidiendutourisme.com/site/accueil.html	www.ylea.eu	https://www.cameroon-tribune.cm/
100	http://www.lyon-france.com/	www.zoomici.com	http://www.lactualite.com/

Appendix D

Gray-scale images of representative web pages of categories touristic, e-commerce, and news

Figure D.1 A gray-scale version of the web page representative of the touristic category.

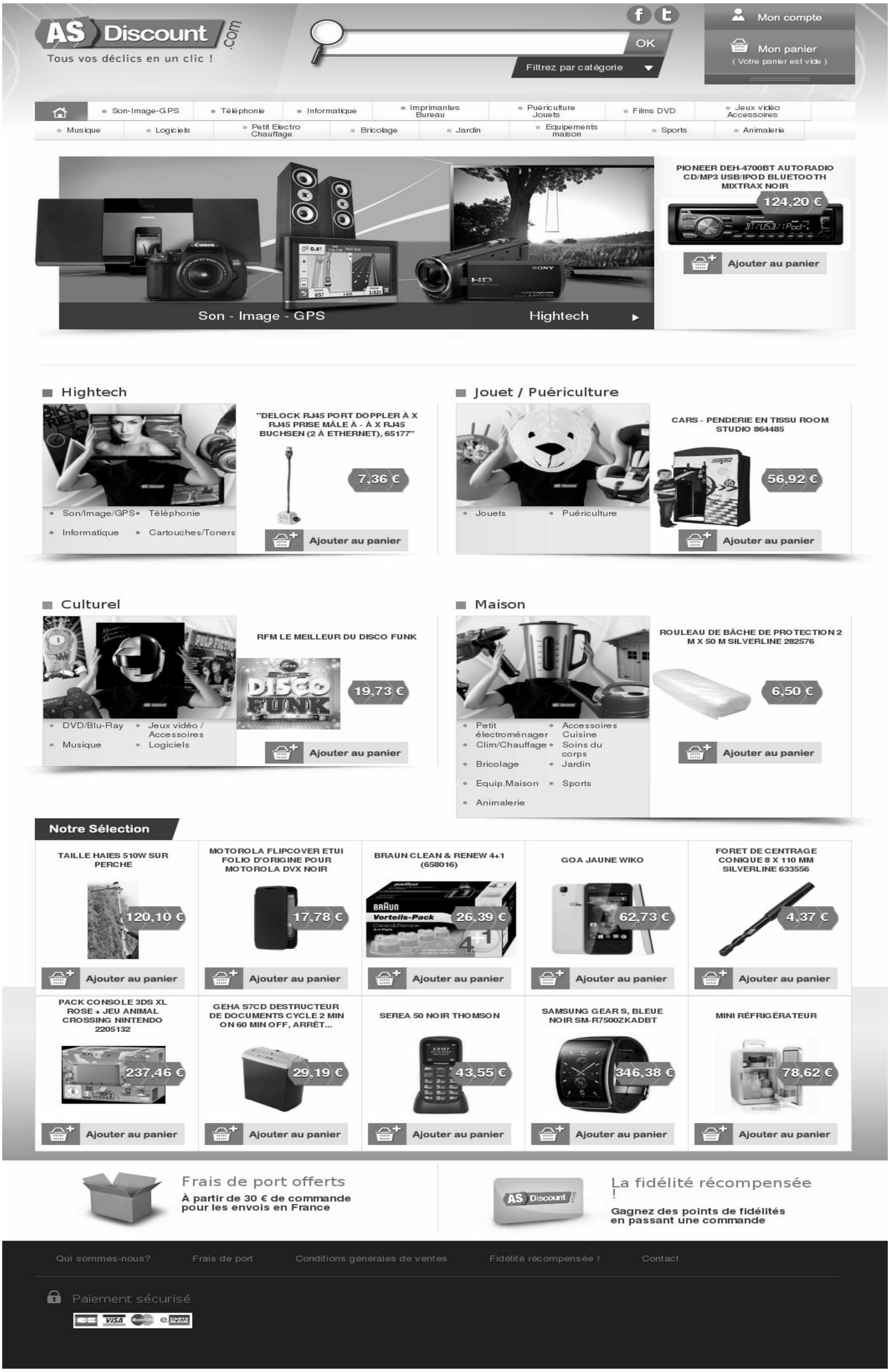


Figure D.2 A gray-scale version of the web page representative of the e-commerce category.

Figure D.3 A gray-scale version of the web page representative of the news category.