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Haptic Perception of Document Structure for Visually Impaired People on Handled Devices

Fabrice Maurel, Gaël Dias, Jean-Marc Routoure, Mathieu Vautier, Pierre Beust, Michèle Molina, Coralie Sann *

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Abstract

The dissemination of information available through the World Wide Web makes universal access more and more important and supports visually impaired people (VIP) in their everyday life. To access this information, VIP use screen readers to extract the textual information, which is displayed on the screen. The extracted two-dimensional information is linearized and is either written in Braille on a special output device or presented by voice output. However, on the one hand, some studies showed that impaired populations prefer to use commonly available software and hardware solutions rather than dedicated specialized solutions. On the other hand, we demonstrated in previous research that the perception of the document structure plays an important role in its memorization. In this paper, we propose to automatically generate vibrating pages from document layout skeletons based on the transformation of light contrasts into low-frequency tactile vibrations. First experiments on digital tablets show promising results in a "Design-for-All" paradigm.

Keywords : Haptic Perception ; Document Structure Skeletons ; Low Frequency Sensors ; Handled Devices ; Design-for-All

1. Introduction

Blindness is defined by a level of visual perception below 1/100 after correction or when the width of the visual field is less than 20 degrees, when the standard is 180 degrees. The World Health Organization estimates that currently (as of September 2011) worldwide, nearly 314 million people are visually impaired due to various causes (e.g. 39% due to cataract linked to the age), of which 45 million are blind. Thanks to advances in medical treatment, the number of blind people is decreasing. However, visually impaired audiences are growing in particular due to low or reduced vision. For example, in France, beyond the corrections due to aging, about 10% of the population is experiencing visual difficulties to varying degrees. An accurate estimate evaluates that from 750,000 births annually about 100,000 people have or will have vision problems. Today, the blind population in France is about 1 in 1000,

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i.e. 77,000 visually impaired people (VIP), of which only 15,000 have learned Braille and 7,000 would practice it on a regular basis. One objective of our research is to improve access to information for blind people in particular considering that its majority does not practice the Braille.

With the invasion of new devices to access to information, increasing developments of worldwide networks such as the World Wide Web and the profusion of electronic documents, there is a clear need of new interfaces to access new content media. In particular, classical solutions proposed for blind people to interact with a computer and its contents show important drawbacks. First, they are usually unsuitable for mobile devices [6] [7] [8] [9]. Indeed, mobility is hardly compatible with the transport of a Braille support, which is also expensive and exclude VIP from the information and work market society. Second, noisy and public environments make it difficult to listen to speech synthesis and voice recognition. Third, previous studies [5] [12] have demonstrated the importance of the overall perception of the document to initiate a cognitively effective interaction. However, no satisfactory solution has been proposed so far to compensate the inability to directly target part of a screen for VIP like any non-disabled user would do when reading. We usually refer to this situation as the first glance, from which any reader can take into account in a blink of an eye the document layout and as a consequence to the document structural semantics. Indeed, blind users must usually browse document contents sequentially. This process is commonly referred to as a linearized one, although web pages structures are two-dimensional [3] [4] as illustrated in Figure 1.

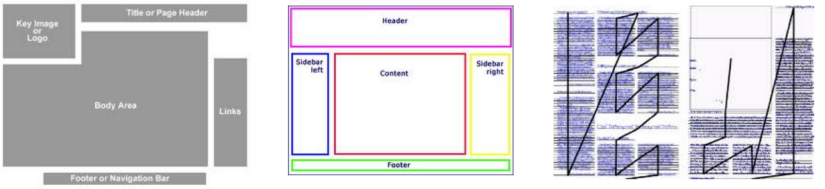

Fig. 1. Different web page and document layouts

Accessing to document semantics is a challenge especially to allow high-level operations like reading diagonally, prioritizing, storing information, quickly finding relevant information, pointing directly to any information present in a web page, to name but a few. As a consequence, the purpose of our research is to understand how to transpose the visual architectures and interfaces of documents in a non-visual perception.

For that purpose, we present a non-visual navigation solution that exploits the spatial two-dimension information of web pages interfaces and documents. In particular, we propose to automatically generate vibrating pages from document layout skeletons based on the transformation of light contrasts into low-frequency tactile vibrations. For that purpose, a vibro-tactile access strategy to documents and interfaces is proposed by using actuators that consist in micro vibration motors located in the active hand. The information, in terms of pixel and/or logical structure is provided by the tablet and transformed by the actuators using localized vibrations with adjustable levels or frequencies. With this device, we aim to replace the classical visual exploration of a document (the "first glance") based on a luminosity vibration by a tactile vibration using the actuators. As such, compared to existing works [6] [7] [8] [9] [10], we propose a new solution, which can be applied to any digital display (e.g. digital screens, multi-touch screens, bendy screens, holographic displays, surface displays), proposes a new perception sensation based on vibrations, runs in real-time and can easily be adapted to handled devices. First experiments on digital tablets show promising results in a "Design-for-All" paradigm. Finally, we will show how the power and the applications natively embedded in digital tactile tablets may allow proposing further improvements for our solution.

2. Commercial Context for Visually Impaired People

Speech synthesis and Braille are the main solutions that have been used to allow access to computers by blind people. These two interactions (touch and voice) are commonly used as outputs for screen readers. The screen reader is a client support related to the operating system of the computer, which interprets what is displayed on the screen and transfers it as text to a Braille device or speech synthesis device.

Braille displays are electromechanical devices that connect to a computer and display Braille characters in real-time. However, these devices are fairly complex and expensive. They usually cost between 5,000 and 10,000 euros.

Speech synthesis engines convert text into artificial speech. Based on linguistic processing, the text is analyzed and transcribed into phonemes, which are then processed using signal processing techniques in digital sounds. Within the context, according to a WebAIM survey in February 2009, several speech screen readers exist, mainly Jaws from the Freedom Scientific, which is used by 74% of Internet blind users and Windows-Eyes from GW Micro with 23% of the market. As an alternative to screen readers, ineffective on the World Wide Web, blind people can surf the web using “talking” browsers, which propose simplified reading of the available information. Such systems include Braille-Surf or more recently MozBraille, BrailleNet and IBM HomePage Reader. Since 2005, Opera has developed a version of its Internet browser to read selected portions of texts. For their part, Firefox and Chrome offer voice extensions such as FireVox and ChromeVox. In particular, these systems announce the title of the web page as it loads automatically and read the document contents. It is important to note that, regardless of technology choice, the VIP users will never have a global view of the two-dimension document structures. Indeed, the proposed solutions only allow a linear perception of different fragments, which then must mentally be manipulated by the user to reconstruct the overall information. However, in recent years, strongly pushed by Apple's accessibility policy, software solutions have emerged for tactile-oral access of contents from devices with (multi-)touch screens or trackpads. Although other native alternatives are being integrated into systems such as Android and Microsoft Phone, we present the solutions offered by VoiceOver, currently the most successful solution for blind people.

The two principal means of a non-visual access to an Ipad are (1) by piloting a Braille device by a Bluetooth connection and (2) by using VoiceOver, a screen reader with a speech synthesis engine. But mainly important within the context of our work, one can get instant oral information about elements overflown from a gesture on the (multi)touch screen. VoiceOver also includes a virtual drive called “rotor”, which simulates a dial pad to access to commands and other features of the Ipad. An interesting use of the rotor is for web page navigation as it incorporates in its menu standard elements such as headers, links, tables and images. The action on the rotor can then select one item and allow navigating among its different occurrences. Of course, this possibility makes sense when coupled with web spots automatically generated for every page requested through the browser Leopard. Indeed, navigation using screen readers is complicated by the fact that many pages do not meet accessibility guidelines (they are poorly structured or not using proper W3C recommendations), in which case VoiceOver may use information provided by the native browser to create and use virtual tags called web spots. These ones mark key locations of a web page based on its graphics to identify interesting features and ease navigation. According to designers, web spots reflect how a user travels a valid page to identify articles and other interesting readings. Unfortunately, we were unable to find, at the time of this writing, scientific data on the quantitative and qualitative contribution of these non-visual interaction techniques, although it is easy to find numerous examples of non-blind that ensure a positive experience for example in the report of the seminar on Apple integration of people with disabilities held in Paris on 1st February 2011.

Although these contributions go in the right direction, they are greatly facilitated by manufacturer closed architecture and controlled interfaces. This approach can facilitate software design solutions focusing solely on hardware and proprietary applications. Moreover, despite the development of technical aids and devices, no satisfactory solution is proposed to compensate for the absence of this “first glance” that allows an early integration of visual cues useful to control the interaction. Our point of view is that fast perception of all the elements and formatting of a document or interface is heavily involved in offering the reader the ability to point directly to some parts without the need of access to further objects. In particular, we are working on this issue in a more comprehensive understanding of displayed contents through non-visual percepts that promote greater freedom to interact with content. We describe in the next section the current scientific approaches that we think are most innovative in this context.

3. Research Context for Visually Impaired People

Braille allows the representation of characters, punctuation and a part of layout (title, paragraph, tables ...); in terms of either design-for-all or design-for-more [13] approach, we avoid this code in order to include both sighted persons and most of blind people who don’t read it. Few text-to-speech designers saw the need "to go beyond the bound of the sentence (the paragraph or even a hierarchical organization of documents), for a non-linearly reading [14]". Yet, when we examine recent systems, we notice that layout is little used in the calculation of the synthetic

speeches prosody. A proposal was made in this direction in order to transpose the visual architecture of documents toward oral modality thanks to various strategies [12]. The two conclusions of this work are that (1) layout transposition toward intonative patterns improves the efficiency of speech synthesis, but (2) the lack of global and early vision degrades cognitive capacities in comparison with silent reading. An either alternative or complementary solution has to be found in the tactile modality. To solve this issue, very few works have been proposed in the research community.

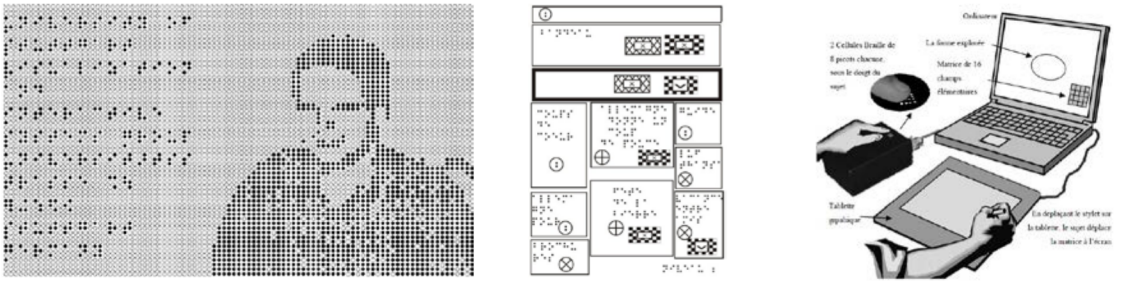

Fig. 2. (a) Pin matrix [6]; (b) MAP-RDF model [8]; (c) Tactos [10]

First, [6] propose a tactile web browser for hypertext documents, which renders text and graphics for visually disabled people on a tactile graphics display and retains the two-dimensional structural information of the document. In particular, the authors implemented two exploration modes, one for bitmap graphics and another one for Scalable Vector Graphics (See Figure 2a). Although this solution is technically interesting, it needs a pin matrix device, which is expensive and cannot be extended to handled devices. Moreover, disabled people tend to prefer to use the same software and hardware as non-impaired people. As such their societal inclusion is made easier.

More recently, [7] presented a low cost tactile web navigator device aimed at enabling blind people to have feasible Internet accessibility. In particular, the platform includes a micro-controller that communicates with the browser software proxy transcoder server to acquire the text from a web page. The text is subsequently displayed using an array of solenoids giving the required tactile sense. The visually impaired users are then able to use their tactile sense to recognize the text in Braille language. Once again, this solution needs specific hardware, which in particular, cannot be applied to mobile devices. Moreover, the main purpose of their research is based on text sensory and not on document layout perception.

Within the context of our work, [8] certainly propose the most innovative solution, which consists in detecting the significant visual information in a pictures/documents by extracting their properties and rearranging them for a specified accessible output (see Figure 2b). Their approach relies on the efforts made in the field of digital documents accessibility (mostly metadata) along with image processing and content-based image retrieval. Their model, called MAP-RDF, is implemented into a general hardware/software framework, which provides tactile or/and oral outputs. The solution is interesting as it provides the blind users with an overview of the web page structure, i.e. the document structural semantics. However, this approach can only be applied to well-structured documents, which contain metadata and do not apply to most web pages, which rarely contain this information. Moreover, the processing power needed to perform the web page analysis may not allow real-time processing.

In order to solve the problems evidenced in the literature, we propose an idea based on the work of [9], where the authors present experiments based on the device called Tactos [10]. Tactos includes three different elements: a computer, tactile stimulators (two Braille cells with 8 pins) and a graphics tablet with its stylus (see Figure 2c). The whole framework allows the recognition, in blind mode, of writing and/or drawing on the computer screen. Each shape or drawing displayed on the screen is haptically perceived as a result of the movements of the stylus on the tablet, guided by the subject's hand. The subject feels the stimulators being activated under the finger of his hand each time the cursor crosses the shape on the screen. Similarly, we propose a framework, which is used to haptically perceive the document layout skeleton. For that purpose, the layout of a given web page should be transformed into a skeleton of its structure (e.g. by using the VIPS architecture [11]). Then, the blind user can scan the screen of any digital device (e.g. digital screens, multi-touch screens, bendy screens, holographic displays, surface displays as

shown in Figure 3) with a sensor, which automatically transforms light contrasts into low-frequency tactile vibrations. As a consequence, the layout is transformed into vibrating pages, which may allow the access to the document structural semantics. As such, compared to [10], we propose a new framework, which (1) provides a new perception based on vibration, (2) is specifically aimed at document structural semantics discovery for VIP, (3) can be used on any digital display, (4) runs in real-time and (5) is easily adapted to handled devices.

Fig. 3. (a) Bendy screens; (b) Holografic screens; (c) Surface displays.

4. Vibro-Tactile Access to Documents and Interfaces

The objective of our work is to improve the navigation for blind people within web pages displayed on digital tablets. For that purpose, we propose to evaluate a new strategy to access to vibro-tactile documents and interfaces, through actuators placed on the active hand. The information captured in terms of pixels and/or logical structures will be provided by the tablet in contact with the hand and then translated by the actuators in the form of localized vibrations with variable intensity and frequency. With this device, our ambition is to replace the visual scanning ability, based on the capture of the light produced by the digital screens, with manual exploration ability, based on vibro-tactile perceptions of actuators. In Figure 4, we present our first prototype.

Fig. 4. (a) Framework Architecture; (b) Vibro-Tactile framework; (c) Framework with the Digital Tablet.

The embedded system realized allows to measure light under one finger in contact with the screen and to transform the measured light intensity I into a stimulus that consists in a level of vibration V using a mini vibration motor. This motor is also in contact with the finger and thus allows to "perceive" using a vibration level of the light intensity beneath the finger. At the moment, only a simple and linear relationship is used between I and V. The system has been designed to be simple, cheap, as flexible as possible and to be able to work without the help of the computer as opposed to most existing works [6] [7] [8] [9] [10].

To fulfill these different requirements, a Lego™ mindstrom brick has been used as embedded system. This device offers different facilities such as, built-in Bluetooth communication port, LCD screen, 4 I2C ports to connect sensors and different programming languages such as Labview or C. A battery can supply power to the system, but stabilized DC can also be used to power the sensor and the micro motor. The autonomy of the system is longer than one day, which gives the opportunity to the researchers to test different configurations without taking care of the electrical supply. The light sensor consists in an integrated photodiode associated with an operational amplifier that

provides a voltage directly proportional to the light intensity received by the photodiode. This sensor has been packaged into an opaque box to remove parasitic light and a hole with a diameter close to 1 millimeter square has been realized to select a small area of the screen to be accessed by the sensor (this situation is variable depending on the grain of the shapes to be discovered). Then, the voltage at the output of the sensor has been digitized using a low cost 8 bit analog to digital converter with an I2C port (reference 8891). This electronic device also integrates a digital to analog converter used to pilot the micro-motor. Finally, a bipolar transistor is used to supply enough power to the micro-motor from precision micro-drives. The hardware performances and especially the frequency range are limited by the micro motor. With the selected motor, frequencies are compatible with the physiological range of frequency with a maximum value around 200 Hz. With these standard devices, the cost of the system is less than 400 euros with the maximum cost coming from the Lego™ bricks. In the future, cheaper systems can be realized with the development of a specific embedded micro-controller.

5. Pre-Tests and Evaluation of the Framework

To get a first idea of the possibilities offered by the proposed device and to prepare the establishment of a strong experimental protocol with visually disabled people, we chose to first perform a series of experiments with sighted users. For this purpose, four ordered tasks have been proposed and filmed, for future cognitive analysis, based on 15 different sighted users with their eyes closed as shown in Figure 5a. In order to get acquaintance with the device, each one of the 15 users were asked to proceed to different training experiments. In particular, they had to "feel" the vibro-tactile perception without eyes closed based on the shapes presented in Figure 5b.

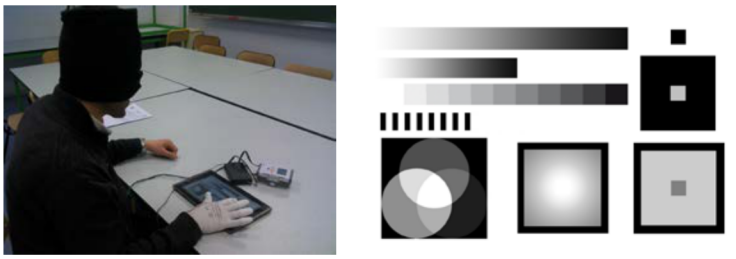

Fig. 5. (a) Evaluation Conditions; (b) Training Conditions

Then, the evaluation task was threefold. First, they had to recognize one of the basic shapes proposed in Figure 6a, 6b and 6c. Then, the users had to discover different elements from the four different shapes. The third experiment was defined as recognizing one of the aforementioned shapes when displayed together. Finally, users had a more challenging task, which was based on the memorization and reproduction of one of the three unknown shapes simulating different web pages layouts as illustrated in Figure 6d, 6e and 6f. Overall, the duration of the experiments ranged from 15 minutes to 30 minutes, depending on the tasks.

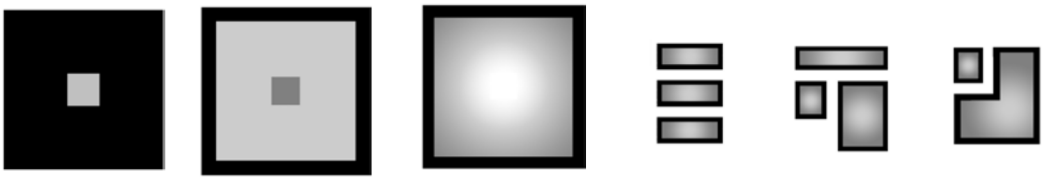

Fig. 6. : Basic Shapes (a) NT2; (b) NT3; (c) NTG; Shapes (not to scale) Describing Possible Web Page Layouts (d) IDP1; (e) IDP2; (f) IDP3

5.1. Pre-Tests 1: Learning Task

This task was settled to test the prototype on various graphical objects presented together on the screen. As such, the user could both feel and see different levels of gray, gradients from white to black gradients and various hatches

and squares, which were differentiated by their edge, their background and the color of their center as illustrated in Figure 5b. In particular, this task allowed the users to (1) perform different experiment with different scanning speeds to choose the most suitable one for detecting the overflight of a border or the passage of a gradient; (2) to train specifically on the squares used in the following tasks by memorizing the various transitions to find their center.

5.2. Pre-Tests 2: Recognizing Shapes

This second pre-test was settled to evaluate how the user would recognize some elements from the basic shapes already presented in the training session, but this time in a blind mode. The basic shapes in Figure 6 were announced and presented successively in a random position on screen. The user had then to find the square center in the middle of bigger square. The interest of this task was to get a first feedback on how the user would react based on the different backgrounds and borders to move his finger in the right direction, and hopefully recognize the shape.

For that purpose, we created three different shapes with different transitions. Figure 6a (NT2) proposes a two-transition shape. Indeed, to find the center of the square, the user would have to experiment two different transitions: (1) from white to black and (2) from black to gray. Figure 6b (NT3) shows the same situation but with three transitions and finally, Figure 6c presents a compromise shape with a gradient transition to analyze the reaction through a continuous decreasing intensity from the micro-motor. Within this task, the time to recognize the shape was measured. In particular, a time longer than 1 minute to recognize the shape on the screen was considered a wrong answer. The empirical trends that will support our future assumptions are summarized in Table 1.

Table 1. Results of Pre-Tests 2

Shape Name	Average Time in Seconds	Number of Errors	Standard Deviation in Seconds
NT2	28	2	19
NT3	36	6	16
NTG	22	3	9

Various feedbacks came back several times from the users and need to be clarified. First, the vibration is not particularly pleasant, even the users forget it or find it significant for its aid in recognizing the shapes. Second, the exercise requires a lot of concentration so that the user does not to get lost in the space of the screen. Finally, the borders are well perceived by the users.

This work shows that the gradient representation of the space (NTG) is on average more efficient to find the center of the square. On the other hand, recognizing NT2 is an interesting experiment because a more detailed analysis of the videos taken to analyze the users' behaviors shows that the center is actually found more quickly by a quick scanning technique, but users prefer to refine their feelings before risking to give an answer. Oppositely, for the gradient experiment, the center is announced as soon as it is found. However, some errors occur with NTG as the radial gradient from medium gray to white can produce a confusion between the center and the outside the shape. This is mainly due to the lack of vibration sensibility. Moreover, the NT3 situation clearly shows worst results and essentially confirms that a gradient solution allows better recognition. So, these pre-tests lead us to formulate the following assumptions:

1. A black background will be effective for a fast but approximate shape recognition;
2. A gradient background from dark gray to light gray will be useful for a precise search but slower;
3. 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.

5.3. Pre-Tests 3: Recognizing and Differentiating Shapes

In this task, the user had to find and recognize one of the different squares highlighted in the previous task (NT2 or NTG) in a blind mode. As such, the user would have to perform recognition and differentiating phase. For that

purpose, two groups of six users had to recognize one of these two forms. The results reported in Table 2 show that if both forms were relatively well recognized, it seems faster to recognize a black square rather than a square with a gradient perception, although this second shape can be seen as a multi-transition task. Furthermore, the results indicate a greater dispersion for NTG. From these results, we drew the following assumptions:

1. In order to recognize the different areas of a document, black boxes will be sufficient;
2. The semantics of the gradient can be used for fine-grained recognition and differentiation, such as allowing an understanding of the distance from the finger to a border since the acceleration of the vibration is inversely proportional to the size of the degraded.

Table 2. Results of Pre-Tests 3.

Shape Name	Average Time in Seconds	Number of Errors	Standard Deviation in Seconds
NT2	17	1	8
NTG	28	1	16

5.4. Pre-Tests 4: Recognizing and Differentiating Unknown Document-like Shapes

Fig. 7. Drawn Shapes (a) for IDP1; (b) for IDP2; (c) for IDP3.

Our final pre-test is the ultimate experience to validate our assumption that vibrating pages can be used to access the structural document semantics by scanning the document structure skeleton via the transformation of light contrasts into low-frequency tactile vibrations. For that purpose, the users had to recognize the Figure 6d (IDP1), Figure 6e (IDP2) and Figure 6f (IDP3) shapes, which had never been presented to him and present possible web page structures. In particular, 3 groups of 5 people had to recognize one of these three forms in order to balance the possible bias of the experiments. The exploration time was not limited and varied between 2 and 8 minutes. Then, when the subject wished to removed his blindfold, he had to immediately reproduce the perceived shapes. In order to give a score to each experiment, we proposed the following scheme, which results are summarized for 9 marks in Table 3:

- 3 points were attributed if the number of elements was respected (1 point is retrieved if one more shape is added or omitted. In particular, the “L” element of IDP3 counts for 2 points);
- 1 point was afforded for correspondence with the original of each drawn shape (with a maximum of 3 points);
- Between 0 and 3 points were given for the reproduction quality of the configuration of all the items together.

Table 3. Results of Pre-Tests 4

Shape Names	Average Score in Seconds	Standard Deviation in Seconds
IDP1	5.4	3
IDP2	5	2
IDP3	4.8	3

These experiments show that the gradual decrease of the marks seems to correspond to the increased difficulty of the proposed shapes. That said, they are all above average (i.e. 4.5) but vary individually from 1 to 9. It is important to notice that at least one person per group obtained the maximum score of 9. Some results are presented in Figure 7.

Based on the analysis of the different experiments, we can conclude that despite a short learning phase and a limited quality vibro-tactile feedback, a visually disabled user can seek, identify and use patterns to perceive the visual architecture of a digital document and access to the "first glance" of a web page based on a cheap, adaptable hardware framework with a new vibro-tactile perception paradigm.

6. Conclusions and Perspectives

In this paper, we proposed a new framework, which (1) provides a new perception based on vibration, (2) is specifically aimed at document structural semantics discovery for VIP, (3) can be used on any digital display, (4) runs in real-time and (5) is easily adapted to handled devices.

In particular, we first propose that the document layout is identified based on different available techniques, such as image processing, DOM structure retrieval or visual content structure [11]. Then, the visually disabled user is able to access to the document structure semantics, as a non-disabled user would in a blink of an eye by a diagonal reading, by using a vibro-tactile perception. For that purpose, we built an embedded system, which allows to measure light under one finger in contact with any digital screen and to transform the measured light intensity I into a stimulus that consists in a level of vibration V using a mini vibration motor. As such, web pages are transformed into vibrating pages from document layout skeletons based on the transformation of light contrasts into low-frequency tactile vibrations. The first results based on the exploration of vibro-tactile world seem particularly interesting in the context of early access, comprehensive and non-visual configurations carried by the documents layouts. However, successfully providing the blind population with non-linear access to texts and interfaces is an old challenge, that we want pursue by first proposing a strong experimental protocol with visually impaired people. For that purpose, we are currently working with Psychologists, Computer Scientists and Electronic specialists to quickly achieve "Design-for-All" non-expensive and non-intrusive solutions.

As such, we plan to include many different improvements into the prototype in short terms. In particular, we are already working on the transition to a colored world by introducing a frequency modulation of the vibro-tactile actuators, so that the blind user may perceive the notion of hot, warm or cold colors. Hardware improvement in the system will also concern adding a derivative proportion in the relation between V and I to increase the contrast. Future work will also concern the introduction of noise and more especially low frequency noise to test if the framework could make the stimulus more pleasant. We also plan to leverage our actuator to take advantage of multi-touch displays. In this case, the sensor would be replaced by direct communication between the digitizer and the effector. Such a software sensor device would allow a non-intrusive architecture. Finally, we may move towards a multi-modal solution where non-visual interactions could combine vibro-tactile and oral perceptions, as our experiments showed that the users were using both the vibrations of the actuator but also the sound of the power engine to navigate into the non-visual world.

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