**Proiect KNOWLEDGE - POSDRU/159/1.5/S/134398**
*Dezvoltarea resurselor umane din cercetarea doctorală și postdoctorală: motor al societății bazate pe cunoaștere*

UNIVERSITATEA **POLITEHNICA** DIN BUCUREŞTI

**Facultatea Automatică și Calculatoare**

Departamentul de Calculatoare

Nr. Decizie Senat 237 din 02.09.2015

# TEZĂ DE DOCTORAT

***Instrumente Informatice Asistive și Educaționale pentru Persoanele cu Deficiențe de Vedere***

***Educational and Assistive IT Tools for Visually Impaired People***

**Autor: Vasile-Alexandru Butean**

**Conducător de doctorat: Prof. Dr. Ing. Florica Moldoveanu**

**COMISIA DE DOCTORAT**

| | | | |
|---|---|---|---|
| Preşedinte | Prof. Dr. Ing. Adina Magda Florea | de la | Universitatea POLITEHNICA din București |
| Conducător de doctorat | Prof. Dr. Ing. Florica Moldoveanu | de la | Universitatea POLITEHNICA din București |
| Referent | Prof. Dr. Ing. Vasile Manta | de la | Universitatea Tehnică „Gheorghe Asachi” din Iași |
| Referent | Prof. Dr. Ing. Bala Constantin Zamfirescu | de la | Universitatea “Lucian Blaga” Sibiu |
| Referent | Prof. Dr. Ing. Nirvana Popescu | de la | Universitatea POLITEHNICA din București |

Bucureşti, 2015

## *Acknowledgements*

I feel very lucky to have by my side a lovely wife, pleasing family, remarkable friends and to be part of an admirable research group. I am thankful for all the support they offered.

I would like to express my appreciation to my advisor, Prof. Florica Moldoveanu. For me, she is a research model, an infinite resource of patience, dedication and professionalism. Every time I needed an advice or a solution she provided prompt assistance and valuable help.

I am very grateful to Prof. Alin Moldoveanu, my co-advisor, who inspired me from day one. He is the person who motivated and contributed to all my research ideas. I will not forget my entire life that he helped me with important feedback, precious ideas and friendly pieces of advice.

This work has been funded by the Sectoral Operational Programme Human Resources Development 2007-2013 of the Ministry of European Funds through the Financial Agreement POSDRU/159/1.5/S/134398."

The projects presented in this thesis have received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 643636 "Sound of Vision".

The results presented in this research were possible due to the help of National Association of the Blind People in Romania / subsidiary Sibiu and other individual subjects who have offered to be volunteers for testing and feedback sessions.

# Table of Contents

# 1 Introduction

## 1.1 Motivation and purpose

Around the world there are over 285 million people with sight problems, 39 million being completely blind and 246 with low vision [5]. Visual impairment is unequally distributed across age groups. About 82% of all people who are blind are 50 years or older, although they represent only 19% of the world's population. Due to the expected number of years lived in blindness (blind years), childhood blindness remains a significant problem, with an estimated 1.4 million blind children below age 15.

The market trends [90] reveal that modern devices like smartphones and tablets are becoming cheaper and thus accessible to everyone. In schools these devices are becoming popular and interactive learning tools [91] are being developed using modern technology advantages.

Due to this massive growth in the development and sales of mobile devices, they automatically become less pricey and, inherently, more accessible to a wider public.

A very hard thing to imagine for people with healthy vision is how visually impaired people [14] perceive the world around them, colors, shapes, etc. Because of the fact that they never saw how a line or a curve looks like, or what the color of the sky in the morning is, they simply cannot visualize the beauty of God's creation.

Based on the brain's capabilities to rewire and distribute resources from affected areas, the sensors' migration from vision towards touch and hear, balances the scale and importance of these senses [92]. Therefore, the brain area responsible for touch and hearing performs much better. In order to benefit from their unique aptness and obtain maximum results, the entire learning process [93] of visually impaired people should focus mainly on sound and haptics.

Given this impressive information presented above, the choice of topic is motivated by the aspiration to improve and innovate the learning process for visually impaired people using modern educational and asistive tools powered by the latest touchscreen technologies, smart devices and a multitude of futuristic gadgets.

## 1.2 Thesis outline

This PhD thesis is structured on ten chapters.

The first chapter is a straightforward introduction, explaining the motivation and purpose that guided me to focus my research on helping visually impaired people get used to modern assistive devices, gadgets and touchscreen applications.

The second chapter shortly presents basic information about visually impairment, statistics, classifications, environmental perception and assistive technologies.

The third chapter offers an overview on the state of the art research articles, tools and applications developed using modern touchscreen technologies and devices in order to assist visually impaired people.

The fourth chapter presents original contribution in the area of asistive tools and describes the development process and logic for a touchscreen application dedicated to visually impaired people. The application has a series of learning tools meant to encourage users to use touchscreen devices and accessibility features in a unique way.

The fifth chapter offers a summary on the state of the art research articles and gadgets used to assist visually impaired people in the process of perceiving colors using vibration stimuli.

Based on the existing concepts on perceiving the colors haptically, a unique development method is described into chapter six. Using a standard Xbox controller with powerful vibrating motors connected to the application, users can learn and perceive basic colors.

The seventh chapter reveals information about the experiment, charts and statistics on how the visually impaired volunteers interacted with the new applications.

General conclusions and original contributions are presented in chapter 8.

Chapter 9 displays a list of published papers during my PhD studies.

Chapter 10 lists the references used for this thesis.

Chapter 11 contains annexes, code snippets and technical implementation details.

# 2 Visual Impairment

Visual impairment, also known as vision impairment or vision loss, is described as an obstruction of one or more functions of the eye or visual system [1]. The concept [3] of blindness refers to total or almost complete vision loss. However, there are people completely blind, and others that are diagnosed with "legal blindness". The concept [2] applies to those that haven't entirely lost their sight, but cannot distinguish objects further than 20 feet from them. As a comparison, a person with normal vision could easily see objects from 200 feet away [7]. Blindness and visual impairment may drastically affect quality of life. As a consequence, people face difficulties in their day-to-day activities, such as walking, driving, writing, or even socializing [4].

Vision impairments alter [1]:

- the intensity or accuracy of vision (visual precision);
- the spatial area in which objects can be observed (visual fields);
- color perception;

There are many possible causes for vision impairment [1], but the most frequently encountered causes are uncorrected (Fig. 2.1) refractive errors:

- Myopia;
- Hyperopia or astigmatism (43%);
- Cataracts (33%);
- Glaucoma (2%)

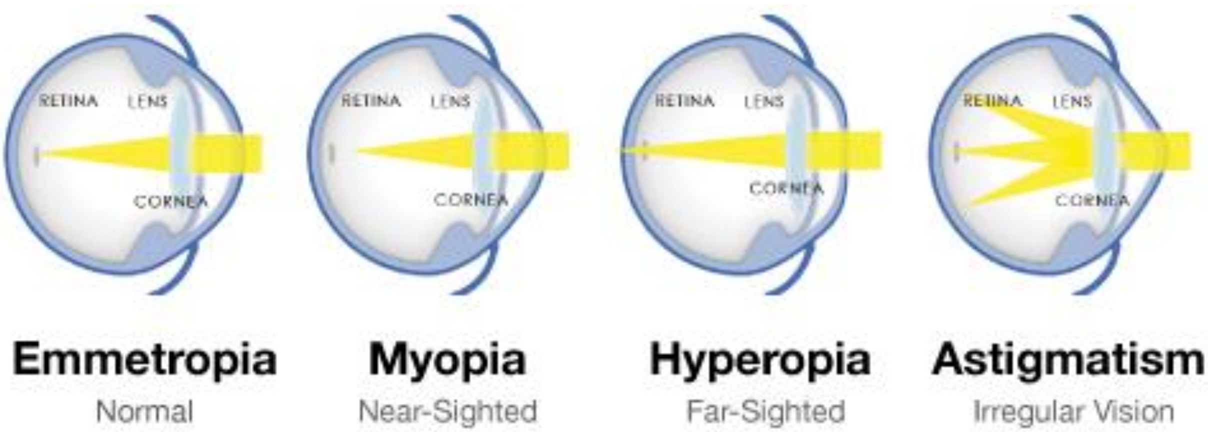


*Fig. 2.1 Causes for vision impairment [24]*

Other disorders that can lead to visual problems encompass age related macular degeneration, diabetic retinopathy, corneal clouding, childhood blindness, and a number of infections [5]. Moreover, many people suffer from monocular vision, which means they have precise vision in one eye, but cannot see with the other [6]

Overall, in spite of the growing number of elderly population, the number of visually impaired people has diminished worldwide over the last 20 years [1]. This decrease is due to:

- general socioeconomic development;
- coordinated public health initiatives;
- expanded availability of vision care services;
- general understanding of population about how to avoid or solve issues connected to visual impairment (surgery, refraction devices, etc.);

Since the early 1990s, significant progress has been made in the following fields [22]:

- governments implemented national programs and policies in order to anticipate and manage visual impairment;
- ophthalmology services intensified and gradually integrated into primary and secondary health care systems, concentrating on offering qualitative and affordable assistance and recommendations;
- campaigns dedicated to increasing awareness and knowledge regarding visual function importance;
- stronger government leadership on international partnerships, with increasing engagement of the private sector;

In May 2013, the 66th World Health Assembly voted favorably for the “Global Action Plan for the Prevention of Avoidable Blindness and Visual Impairment 2014-2019 - Towards Universal Eye Health” [10]. Its purpose is to decrease the number of visually impaired people through global public health programs and offer access to quick, qualitative services. 194 states, part members of the World Health Organization, took this commitment and initiated a series of governmental health programs.

## 2.1 Statistics

According to World Health Organization [22], an estimate of 285 million people is visually impaired worldwide: 39 million are totally blind while 246 have low vision. The population predictions up to 2050 assume that the number of vision impaired people will rise considerably [21] (Fig. 2.2).

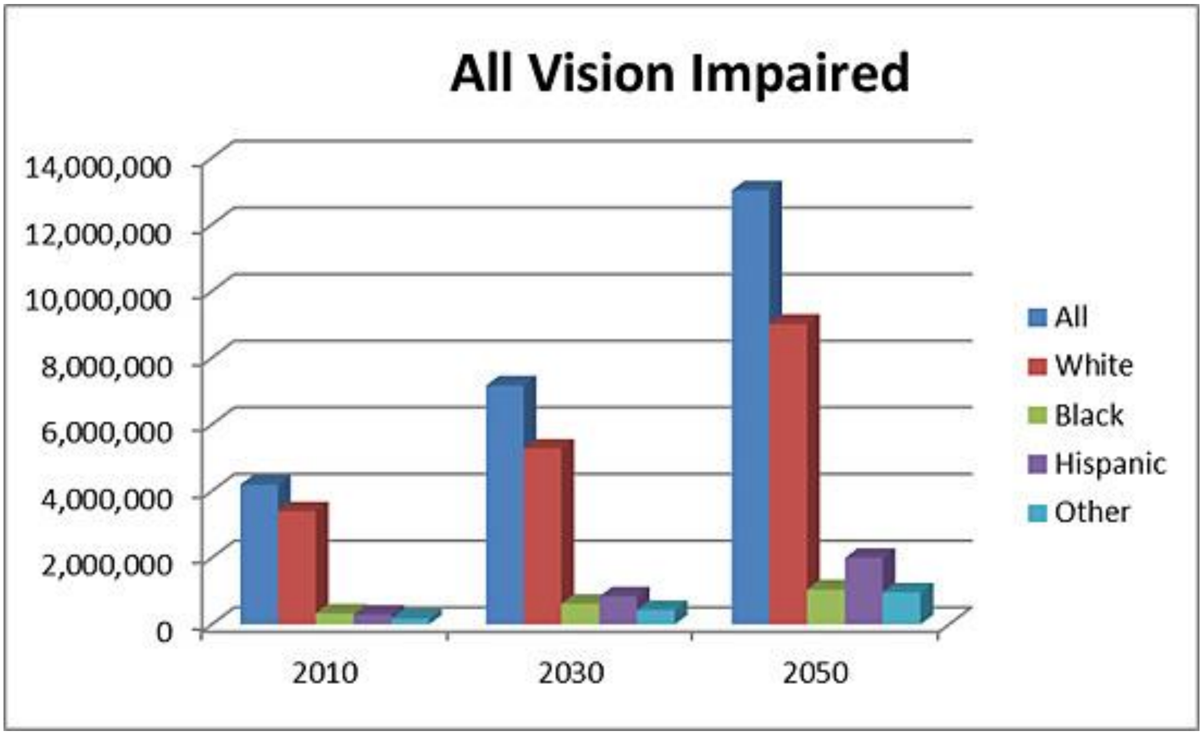


*Fig.2.2 Projections for Vision Impairment (2010-2030-2050) [25]*

Two categories of people can be easily distinguished. People aged 50 and above represent almost 65% of all people suffering from visual impairment problems; they also represent around 20% of the world's population. On the other hand, 19 million children below age 15 are also diagnosed with visually impairment. Over 65% of these children suffer because of refractive errors, an illness that can be quickly corrected. However, 1.4 million children are permanently blind and have to deal with their disease for their entire life.

As stated in the report for the 2012 National Health Interview Survey [8], out of 20.6 million American adults that expressed experiencing serious vision loss, 12.4 million were women while only 8.2 million were men.

In Europe it is estimated that there are more than 30 million blind and partially sighted people [9]. In average, 1 in 30 Europeans suffer from sight loss. At the same time, 1 in 3 individuals over 65 face vision loss. In fact, 90% of the visually impaired Europeans are over the age of 65. Furthermore, statistically there are 4 times more partially sighted people than blind ones.

At a global scale, 80% of visual impairment problems can either be prevented or cured with appropriate care and treatment [1]. This means that improving the state of the world’s eyesight is a realistic goal. However, roughly 90% of visually impaired people live in developing countries. Many of these countries have deficient medical systems and this represents an impediment in the attempt to solve the problem. If better programs would be set in place, the number of visual impaired people could be remarkably reduced.

[6] It is well known that individuals with vision impairments can successfully work at a vast range of jobs and can be trustworthy employees. However, many businesspersons discriminate and exclude them from specific activities based on different judgments about vision impairments or false suppositions that hiring them would be more costly or too dangerous. Others simply fear that visually impaired people would get injured or cause accidents at the workplace.

The average unemployment rate of visually impaired people of legal working age is over 70% [11]. Nordic countries like Denmark, Finland, Sweden and Norway has an average unemployment rate for blind people of 60%. The situation is even worse in Central and Eastern European countries:

- Poland (70%)
- Germany (72%)
- Romania (75%)
- Hungary (77%)

In countries like Germany, there are legislative instruments forcing organizations with over 20 staff members to hire at least 5% of blind or visually impaired people [12]. If companies do not embrace the legislation, employers must be prepared to pay an additional tax. In spite of these severe measures, many employers refuse to hire visually impaired individuals and chose to pay the taxes.

Apart from the employment discrimination, most of the blind and partially sighted people are also affected by the lack of social interaction.

## 2.2 Classification

According to the International Classification of Diseases [13], there are four levels of the visual function:

- blindness;
- normal vision;
- severe visual impairment;
- moderate visual impairment;

Moderate visual impairment together with severe visual impairment are referred as low vision. Low vision accompanied by blindness form the visual impairment cluster.

A person suffering from moderate or severe visual impairment cannot be cured and brought to a normal level, regardless of the treatment, eyeglasses, contact lenses, drugs, or surgery [15]. In this situation, the problem comes from the loss of visual acuity, meaning that the eye cannot distinguish objects as clearly as usual, or a loss of visual field, suggesting that the eye cannot capture from a single view the entire surrounding area, forcing the individual to move his eyes or turn his head or body.

There is also another cluster of terms used to define the different levels of vision disability [13]. These terms are: Partially-Sighted, Low-Vision, Legally Blind, and Totally Blind.

- partially-sighted - indicates that an individual suffers from a form of visual disability that may need appropriate attention and education;
- low-vision - applies to those individuals who suffer from a more severe loss of vision that is not automatically limited to distance vision. These persons may be capable of reading a journal or magazine at a normal distance with eyeglasses, or may require large-font or Braille;
- legally blind – refers to those who have less than 20/200 vision in their better eye, or a very narrow field of view, generally 20 degrees at its far-reaching point;
- totally blind – concerns people who are unable to see and regularly work with Braille or other non-visual forms of media;

Eye problems and vision disorders eventually cause vision loss. However, visual impairment is more often the result of a functional loss of vision, and less a problem of eye disorder. There are numerous disorders and infections that can also cause vision impairment, such as retinal degeneration, muscular problems, albinism, and corneal disorders.


*Fig. 2.3 A: Normal trichromatic view; B: protanope simulation; C: deuteranope simulation, D: tritanope simulation [23]*

A vast majority of people suffer from deficient color vision [14]. Colorblindness affects approximately 1 in 12 men (8%) and 1 in 200 women worldwide. A general misunderstanding is that individuals with colorblindness perceive the surrounding only in black and white. The truth is that there are numerous categories and degrees of colorblindness (Fig. 2.3):

- Monochromasy – represents the form people think of most often when referring to colorblindness; in this situation people see no colors.
- Protanomaly – also referred to as 'red-weakness', applies to individuals that perceive redness more weakly than normal, both in terms of its "coloring power" (saturation, or

depth of color) and its brightness. As a consequence, the red, orange, yellow, and yellow-green colors appear paler than usual, and the green color is intensified.

- Deuteranomaly - also known as 'green-weakness', refers to individuals that face difficulties in distinguishing the red, orange, yellow and green regions of the color spectrum.
- Dichromasy – concerns people that cannot detect the difference between red, orange, yellow and green.
- Protanopia – affects individuals that perceive a reduced brightness in colors like red, orange and yellow; they may be seen as black or dark gray.
- Deuteranopia – also called green-blind, is a form of colorblindness marked by insensitivity to green; in this case, people affected by this disease are confusing when having to distinguish red from green.

## 2.3 Deafblindness

Deafblindness is a mixture of vision and hearing loss that alters one's ability to interact with other people, communicate, move around, and reach out all sorts of information [16].

Other terms used to describe deafblindness include dual sensory impairment, combined vision and hearing loss, dual sensory loss, and dual sensory disability [17].

Individuals of all ages can suffer from a sight or hearing impairment. They may have this disease from the moment they were born, or their senses got deteriorated later in life. There are many causes that lead to deafblindness, some can be more common while some are rare cases that appear with time [16].

There are four types of deafblindness broadly acknowledged [18]:

- Congenital deafblindness – refers to those individuals that are born with both visual and hearing impairments or lost both senses early in the growing period. Congenital rubella syndrome is one of the most widespread disorders associated with congenital deafblindness. Other common syndromes are prematurity, pre- and perinatal trauma, CHARGE association, and other numerous, less usual, disorders. There are over 80 disorders that lead to visual and auditory losses.
- Adventitious or Acquired deafblindness – includes people who experience vision and hearing losses later in life. This sensory loss may happen at about the same time, or it may arise at separate times and/or be progressive. There are diverse causes that lead to adventitious deafblindness, including diseases that are characterized through symptoms such as high fever, kidney failure, diabetes, meningitis, encephalitis, as well as reactions to drugs. Furthermore, traumas, especially brain injuries caused by automobile or motorcycle accidents, also contribute to the adventitious sensory losses.
- Congenital deafness-adventitious/acquired blindness – concerns people who are born hearing impaired or deaf and during their lifetime they experience an acute vision loss or

blindness. The most frequently encountered syndrome, and in fact, the root cause of all deafblindness, is the Usher Syndrome. Other health conditions that lead to this disease include obesity, extra fingers, as well as mental retardation.

- Congenital blindness-adventitious/acquired deafness – applies to those persons that are born with visual impairments or blindness and who suffer from hearing at some point in their lifetime.

Deafblind people have many different ways of communicating [17]. Usually a person adopts one preferred method, but most often he must adjust his communication technique to meet the needs of the interlocutor. The communication style depends in a large percentage on whether the person lost his hearing first, or their vision first, or both at the same time.

Some of these techniques include tactile sign language, close-vision sign language, fingerspelling, writing notes in large print or Braille, print-on-palm, Cued Speech, gestures, pictures, lip-reading, tactile symbols, and touch cues (Fig. 2.4). Some people with dual sensory loss are able to use auditory methods in which the speaker talks in slow, clear, speech and from a short distance from the listener's ear or assistive listening device.


*Fig. 2.4 Braille Sense U2 Communicator [26]*

## 2.4 Social impact

The visually impaired individuals along with their families face serious social challenges [19]. Inevitably, visual impairment interferes with numerous quotidian activities. In the case of adults, the chances to get hired are severely limited as is their involvement in various events. To this is often added a loss of social status and self-esteem. The physical limitations and psychosocial consequences of visual impairment cannot be calculated in precise financial terms. However, it is well known that they reduce the quality of life not only for blind persons, but also for their relatives.

Visual impairment involves a rethinking of basic daily activities, such as bathing and dressing, as well as instrumental tasks, like housekeeping and running [20]. In comparison to other frequent age-related disorders, visual impairment affects the capacity of carrying out such activities. Visually impaired adults are facing even bigger activity limitations—and a more abrupt decline over time—than those without visual impairment. Although these patterns show that increases in activity limitations may be the real cause that leads to negative effects of visual impairment on quality of life, this hypothesis has not been directly studied using large groups of adults with an extensive range of visual functioning. Nonetheless, studies using small groups of adults with visual impairments reveal that activity limitations have a small contribution to elucidating the reduced quality of life of visually impaired adults. For example, a study using a sample of 51 respondents diagnosed with bilateral age-related macular degeneration showed that the strong connection between the degree of visual impairment and the depressive symptoms actually diminished with controlled activity limitations, but the relationship continued to be noteworthy.

Another justification for the negative effect of visual impairment on quality of life lies on social resources. Visual impairment is connected to lower social integration and superficial public support, affecting the psychological well-being. The challenges of maintaining supportive social bonds are exemplified by research studies which show repeated expressions of pity or sympathy towards people with visual impairments, as well as social exclusion. Yet, the role of social resources in clarifying the diminished quality of life of people with visual impairments is modest.

Similar to its influence on social resources, visual impairment may decrease quality of life by diminishing psychological resources such as self-efficacy—a term referring to the perceived ability to control one’s life circumstances. Individuals with bigger visual impairments declare less control over their life circumstances and environment, which is associated with lower quality of life.

A method for measuring the losses and advantages of life expectancy due to anticipation, caution and eventual therapy in the case of visual impairment uses a derived assessment called DALY (Disability-Adjusted Life Years) [19], which contains 5 variables. This method includes in one measure the time lived with a certain incapacity and the time lost due to premature mortality. One DALY unit can be perceived as one lost year of 'healthy' life and the burden of disease as a measurement of the gap between existing health status and an idyllic health condition, free of sickness and infirmity.

Certainly, to address the social implications and pinpoint solutions to improve the quality of life of blind or visually impaired people, a set of assistive technology systems must be developed for each particular aspect of life.

## 2.5 Education

Students suffering from visual impairments have special educational needs which are most successfully met through the collaboration of a team formed of professionals, parents and students [46]. In order to meet their distinctive requirements, students must use specialized services, dedicated books and resources in appropriate media (including braille), as well as specific equipment and technology to assure equal access to the basic and specialized curricula, and to enable them to most effectively compete with their colleagues at school but also in the society.

*Fig. 2.5 Teaching a visually impaired student at a photography class [47]*

There must be a full range of program options and support services to support the visually impaired students in the least restrictive learning environment. For the special programs to be used by the students, teachers must follow adequate personnel preparation programs in order for them to understand how to provide specialized services which address the unique academic and non-academic curriculum needs of students with visual impairments. Also, there must be ongoing specialized personnel development opportunities both for staff working with these students and parents.

The special educational needs of all pupils with visual impairments cannot be met in a single environment, even with unlimited financial resources. It is crucial that a team approach be used in detecting and meeting these requirements and that the team must include professionals who have specific expertise in teaching pupils with visual impairments.

## 2.6 Environment perception

### 2.6.1 Sensory substitution

Sensory substitution [43] is a method that helps the blind people to acquire information about the surrounding space by encoding the visual information into tactile or auditory stimuli. It has been demonstrated [45] in various experiments and studies that the visually impaired individuals are able to effectively process these stimuli in order to develop a solid spatial cognitive map of the environment as sighted people do, in the area of the brain that is responsible for the synthesis of visual cues, i.e. the primary visual cortex. Sensory substitution cannot be considered as a pure sense, as it is neither pure vision nor pure hearing, but a subjective perception known as “qualia”. This is due to the fact that sensory substitution is processed in the cortical areas of the brain, but it receives acoustic and tactile sensations from the basic receptive levels (the auditory or the tactile-kinesthetic systems). It has been suggested that the brain areas are “metamodal”, so that the cortices are assigned different functionalities for processing various types of information and not for responding to different sensory modalities. For example, the primary visual area can be elected for processing spatial information, even if it comes in the form of auditory or tactile stimuli and not compulsory as visual stimuli. A certain level of crossmodal plasticity has been recorded as a result of training and long-term development, by establishing strong connections between senses during echolocation, sound localization and Braille reading that resulted in an increased visual activation in the case of early and late blind individuals. Apart from activating the visual cortex, sensory substitution also provides a vision-like perceptual experience, such as the perception of colors or associations with the visual images acquired before the onset of blindness [31]. For instance, the study of Ortiz et al. [32] demonstrated that almost half of the blind subjects who participated in an experiment that involved the use of tactile sensory substitution device recorded phospenes (a phenomenon of seeing light). In most of the cases, the phosphenes corresponded to the direction and shape of the tactile stimulus presented. The results are reinforced by EEG measurements that showed a certain degree of activation in the occipital lobe (the visual cortex) in the case of the blind individuals that claimed to have vision-like perceptual experiences. A special issue that occurs in vision-like perception is the occurrence of visualization, especially in the case of lateblind subjects who have experienced vision in their lives and could be able to activate the visual cortex via visualization or to imagine that they see and object or a scene. The most relevant evidence against visualization in the case or the blind subjects from Ortiz’s experiment is that the light perception appeared automatically and that the tactile sensations diminished as the visual experiences became more dominant [31]. The vision-like processing is further supported by neural imaging and stimulation studies. For example, PET studies [33] showed activation in the visual occipital cortex of the blind participants, but not for the sighted subjects. Another fMRI research [34] demonstrated that the lateral occipital tactile-visual area can be stimulated by using a sensory substitution method for performing object detection and shape recognition tasks.

### 2.6.2 Cognitive maps of the surrounding

Building solid mental maps of the surrounding space is an essential prerequisite for the development of effective orientation and mobility skills that are required for navigating unfamiliar settings [45]. Environmental exploration is based on the dynamic combination of locomotor, sensory and cognitive tasks. Spatial orientation allows humans to locate scene elements and facilitates the interaction with the environment by helping them to reach targets, avoid obstacles, improve orientation and determine their own position in respect with the surrounding objects. Sight, hearing and touch are the sensory modalities that play a fundamental role in spatial perception, as they provide the means of identifying the geometrical characteristics of the environment (size, shape, directionality), as well as determining its depth or spatiality. The brain continuously processes and integrates information from these senses and builds a complex image of the surrounding space that is commonly referred to as the spatial cognitive map of the environment. The sense of touch provides information concerning the elements of the near space, while hearing and vision are able to deliver perceptual knowledge about the objects and events located in the far space, with the remark that hearing is an omnidirectional sense, while the visual field is limited to the frontal plane of the observer [28]. For navigating in an unknown environment, the sighted people use primarily the visual information that is acquired continuously and spontaneously. Thus, as most of the spatial information is acquired through the visual sense, the blind people are seriously deprived of a means of actively interacting with the environment the way that the sighted people do. As a result, they face considerable difficulties in generating a detailed and accurate spatial representation for navigating in their extra personal space. However, the visually impaired individuals have developed their ability to navigate unfamiliar settings by relying on the auditory and haptic cues as the main exploration modalities [30]. We therefore support the idea that providing the adequate spatial information through an alternate sensory channel can contribute to the development of a solid spatial cognitive map of the environment and consequently improve the blind individuals' navigational performance. Moreover, as the construction of a spatial mental representation is a long and time-consuming process, we consider that the visually impaired people can successfully benefit from navigating virtual environments prior to the real ones. Thus, they can learn the spatial configuration of an environment by listening to auditory events or by perceiving the haptic (tactile and kinesthetic) sensations that build up the virtual reality experience [35]. In the last years, the virtual reality techniques have significantly advanced, providing a natural interaction modality between the end-users and the virtual environment. The computer-generated environments offer a wide range of sensorial virtual experiences, most of them visual, but also auditory and haptic. The main advantage of virtual reality technology is that it provides the means for studying and investigating the human cognitive behavior, without having to consider the cost and setup of physical environments [36].

The formation of cognitive maps is influenced by the image scanning process (the constant shift of attention from one object to another in the visual field, aimed to discriminate the components of the visual scene or to focus on a specific details of one target). The purpose of our review is to determine the extent to which the acquisition of spatial information by other means than the visual sense (for instance, by using the auditory and haptic alternative sensory channels) can result in internal cognitive representations that have the same particularities for the blind or visually impaired people as the vision mediated image scanning has for the sighted individuals [37]. Cognitive mapping refers to the ability to synthesize the spatial information and to transform the perceptual stimuli into consistent spatial knowledge and understanding of the environment. Additionally, cognitive mapping is related to the process of storage, recall and decoding of the information concerning the characteristics and general attributes of the spatial environmental phenomena [27]. The cognitive mapping, as the internal representation of the world, plays a fundamental role for providing a sense of spatial awareness, improving the way finding and navigational abilities and refining the orientation and mobility skills. According to Jacobson [27], investigating the cognitive map formation of the blind and visually impaired people is a subject of considerable significance, both theoretically practically. Thus, he identified four motivations for studying the spatial cognitive representation of the vision-deprived individuals. Firstly, cognitive mapping research is able to improve the mobility and independence of the visually impaired people, to enhance the way finding and navigational decision-making abilities and to ameliorate their quality of life. Secondly, the cognitive mapping research is able to provide a rich theoretical and practical documentation for the development of assistive devices for the blind and visually impaired users, concerning the information that needs to be encoded and the modality in which it needs to be presented to the traveler. Moreover, cognitive mapping research can investigate the utility and proficiency of the assistive devices in order to assess their degree of efficiency in providing a rich spatial representation of the environment. Third, the results obtained from the study can be integrated in the development of environmental planning schemes to facilitate blind people interaction. Finally, the insights and understanding provided by the cognitive mapping research conducts to a better theoretical documentation concerning the role of sensory experience (either visual, acoustic or tactile) in the formation of spatial images in general. The mental model of the space incorporates information about spatial relations between the objects, metric distances and other object-related characteristics of the environment. It has been argued that the early blind individuals are able to process the spatial information statically, but they have difficulties in integrating it in a single, unitary perceptual image, due to the lack of mental abstraction required for this type of task. The opinions concerning the spatial abilities of the visually impaired individuals are contradictory in the scientific community. Some studies demonstrated that vision is an essential prerequisite for the development of solid spatial representations, while other researchers demonstrated that the visual stimuli are irrelevant to the formation of effective cognitive maps [38]. For instance, Klatzky [39] showed that the differences between the spatial performance level of sighted, early-blind and late-blind subjects are slight, suggesting that the mental model construction of the environment is not dependent on any prior visual experience.

### 2.6.3 Auditory cues

The hearing sense offers directional and depth perceptual information regarding the targets located both in the near and in the far space [45]. By performing head movements, the ears gather essential information (direction, duration and intensity of the stimuli, distance and range) that converge to the formation of the auditory array that is further processed at a higher level to build up the so called cognitive spatial map [40]. The audio information is essential for the development of spatial and navigational skills. The auditory sense does not require direct contact with the world, as it can be successfully employed in both indoors and outdoors conditions, in both active exploration (where the position of the listener changes in respect with the location of the acoustic targets dynamically) and for passive observation (when the listener is simply an observer who acquires information statically, without interfering with the environment in any way) [27]. The complex sound environments are known as soundscapes [41]. The soundscapes can be described as a subjective listening experience that is different for each person [42]. The multiple sounds that are present in the environment simultaneously can draw the listener's attention in different ways, concerning both their physical properties (intensity or pitch) and their significance and relevance to the listener. Soundscapes are considered to be the acoustic correspondent of landscapes, as they can be segregated into background and foreground sections that are perceived and analyzed perceptually and cognitively both consciously and subliminally [40]. 3D acoustic spatialized systems give the listener the impression that the sound he hears comes from a particular direction in space and that he is surrounded by sound sources all around in the three-dimensional environment in which he is immersed [29]. The use of binaural 3D sounds in virtual reality applications can prove to be beneficial for investigating the spatial perception, sound localization accuracy, orientation and mobility skills and navigational proficiency of both sighted and blind people, without the need of building any physical environments. The applications that build acoustic 3D spaces based on spatialized sounds are commonly referred to as auditory display systems. Recently, they have also been integrated in electronic travel aid devices aimed to deliver an accurate representation of the space through binaural auditory cues [28].

### 2.6.4 Haptic cues

Tactile maps are used to convey information about the spatial components of the environment and also as an important aid for way finding, navigation and mobility learning, with the purpose of extending the knowledge about the environment beyond the practical and physical experiences acquired from direct exploration [45]. The audio-tactile multimedia approach is the result of the combination of tactile and auditory cues in hybrid applications that enhance the spatial perception by applying sound labels to the graphical elements of the maps. The sound stimuli can be synthesized speech or auditory icons (nonverbal audio messages, like the sound of a door opening or the noise of a crowded street). They improve the navigation of the map, provide a rich representation of the environment and replicate the real-world settings at a smaller scale level [27].

### 2.6.5 Orientation and assistive technologies

The orientation and mobility information that is necessary for navigating in unfamiliar environments should be provided at both perceptual and conceptual levels [30][45]. In what concerns the perceptual level, the lack of visual information should be compensated by the use of alternative sensorial stimuli, such as auditory or haptic cues. Regarding the conceptual level, the interest is focused towards the development of the adequate procedures for effectively mapping the space so that it would sustain a comprehensible and practical navigation for the visually impaired users. The humans use 2 main strategies for scanning the extra-personal space: route strategies, which refer to the sequential identification of spatial characteristics and map strategies that are based on acquiring the spatial features and components of the environment from a larger, multi-layered perspective. The blind people use primarily the route strategy for navigation, as they identify and recognize the objects and events linearly and consequently bring together all the information to construct a single, unitary image of the space [30]. The Electronic Travel Aids, the assistive devices that offer mobility to the visually impaired people, can be divided into 2 categories: obstacle detectors (based on laser beams and ultrasound), that offer information about the objects located in the close proximity of the user and environmental imagers, which deliver an acoustic (or auditory-haptic) image of the 3D space. The obstacle detectors present the disadvantage that they are not able to provide a full perception of the environment while, on the other hand, the environmental imagers require a long training procedure and a high degree of distributive attention for analyzing and responding to all the acoustic or haptic stimuli that are delivered to the user in compensation for the lack of sight [28].

## 2.7 Assistive technologies for people with visual impairments

Assistive technology has, as a precursor, any device that is able to help a person with disabilities to meet their daily targets [44]. Thus, for a person who has a broken leg, the TV remote can be seen as an assistive method. Assistive technology is divided into three main categories.

The first one consists of assistive methods which require a minimum of technological input, simple methods and at a low price, such as a plain pencil grip, for example. A second category is based on a fairly advanced technology, which employs electronic components, such as an office calculator or a keyboard. The third category is based on advanced modern technology and electronics, such as a screen reader. Assistive technology is essential, even critical, for some people. In the same way, a person who has to wear glasses will not be able to fulfill their daily tasks without them.

Another classification of assistive technology can be built by taking their purpose into view. Thus, we can differentiate between five major categories:

- Assistive technologies for persons with communication disabilities
- Assistive technologies for persons with concentration disabilities
- Assistive technologies for people with traveling disabilities
- Assistive technologies for people with hearing disabilities
- Assistive technologies for people with visual disabilities.

Assistive technology for people with visual impairments removed a number of existing obstacles in their path education and employment [44] [45] With the advancement of technology, students who suffered from different degrees of visual impairment, have finally managed to complete their homework, to study at home, to engage in various research studies, and even to read any book. At the same time, people with visual impairments can work smoothly on almost any job title available in an institution, as long as their work is largely based on using the computer, without involving a lot of movement in the office which, although would last longer, it still is possible.

Assistive methods are divided into three main categories, depending on the utilization degree of advanced modern technology:

### 2.7.1 Methods that use minimal assistive technology

The best known assistive method of this type is the Braille language. This is one of the oldest assistive methods used by people with visual disabilities. Braille is a way of writing the 26 letters of the alphabet through embossed points. People with vision problems learn to read Braille by moving both hands over the words, from left to right.

Braille was created by Frenchman Louis Braille, in the year 1824, and it is regarded as the most important invention for people with visual disabilities. In the 1960s, over 50% of visually impaired people living in the United States were able to read Braille. Over time, however, due to some laws, schools could not afford to hire and train individuals who were familiar with Braille. Consequently, the number of people with visual impairments who knew the Braille alphabet dropped dramatically.

Another aspect that contributed to this decline was the development of other assistive methods. Between 1998, and 1999, out of the number of 55.200 persons with declared sight disabilities, only 5500 used Braille (Fig. 2.6) as the main tool for reading of a text.

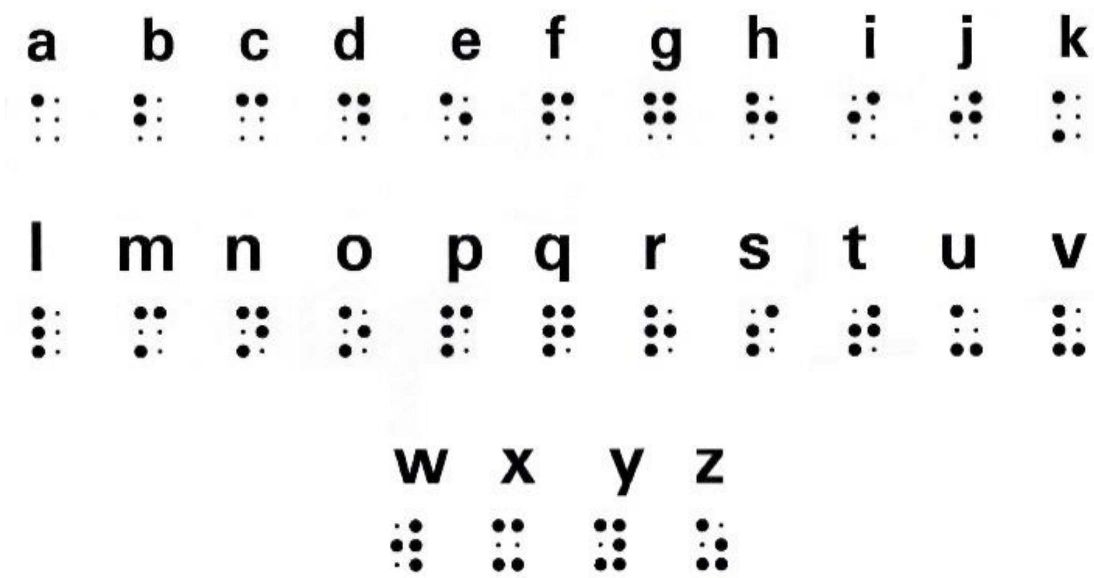

*Fig. 2.6 Braille Alphabet*

Assistive methods for people with low eyesight continued to be developed, even after the advent of Braille. These include:

- matte paper, which improved reading as the paper no longer had reflective properties;
- reading and writing stand, which could be positioned at any desired angle, and could be positioned closer to the eye of the reader;
- thick lined paper that made rows easily visible so that visually impaired persons could write straight;
- markers with tips of different sizes that allowed an easier distinguish between colored writing and underlining;
- magnifiers which enhanced written characters or certain details;
- eyeglasses;

### 2.7.2 Assistive methods with moderate technological input

This category of methods incorporates digital cameras that have different purposes and uses. They have been developed during a rather late period, because they are dependent on the development of technology and electronics. Some of these devices are:

- Keyboards with larger buttons so that the keys could be found more easily by people with low eyesight degree. The closer the keys are to each other, the harder it is for these people to learn their position on the keyboard harder, and the more difficult they find it to write at a high speed.


*Fig. 2.7 Keyboard with larger buttons*

- Keyboards with high contrasting colored keys (Fig. 2.7), which are very useful for people who can distinguish color shades. In this case, the keys are grouped according to several shades of colors.

*Fig. 2.8 Keyboard with colored keys*

- Voice recorder with emphasized buttons (Fig. 2.9) for recording notes, lessons or lectures. Thus, there is no need to write the lessons as it is difficult to do so. They can, instead, record it and re-play the recording, when needed.


*Fig. 2.9 Voice recorder with emphasized buttons*

- Audio books, which are very useful because people with disabilities do not have to struggle reading them, but just listen to them with headphones, as a voice synthesizer renders them in different languages
- Office calculators (Fig. 2.10) with large keys embedded and speaker in order to achieve the calculations as quickly and easily as possible.


*Fig. 2.10 Calculator with speaker and big buttons*

These assistive systems are continuously evolving thanks to both technology development and improvements required by visually impaired persons. Following feedback from these people, the systems are constantly improved.

### 2.7.3 Assistive methods that use advanced technology

One of the most important inventions in this field is the screen reader. This employs the implementation of a modulator which converts text to speech, in order to orally render the writing present on a screen. The message can be heard through headphones or speakers in the default language.

The screen reader does not simply read the text, but it also interprets it slightly, meaning that it will tell if a word is written in a different color or of it is underlined, it will tell if a box is checked or not, and it will highlight the link if there is a word or phrase that makes reference to a website. Through this technology, visually impaired people can use virtually any computer, ATM, or telephone.

A series of programs, applications, and electronics machines was developed so that people with visual disabilities can use and take advantage of modern equipment as easily as possible. Some of these devices and applications are:

- A reading machine (Fig. 2.11) which scans text and, by using a character recognition program, interprets the text. This device can be either independent, if it includes a screen reader through which it can render the writing, either dependent on a computer to which it is connected, so as the writing will be displayed on the monitor and the user can employ a dedicated utility to increase the size of the writing and of the pictures.


*Fig. 2.11 Automatic reader*

- A utility used to increase the screen: it acts like a magnifying glass on different areas of the screen, enlarging the writing and pictures so that they are visible for people with eyesight problems. It may also have extra options embedded, such as generating a contrast between text and background, cursor zoom-in and even reading out loud the titles from the text.
- A utility that zoom into videos, which also acts on the magnifying principle.
- A device for translating text into Braille (Fig. 2.12). It takes a text and, through the use of a dotted strip, embosses points so that they become the reproduction of the same text, only this time in Braille. This band is updated after reading the signs, following the text already introduced up to its completion.

*Fig. 2.12 Text to Braille converter*

- Mobile devices (Fig. 2.13) such as the PDA or the cellular phone. A heavy emphasis falls on these devices as every operating system maker tries to improve their accessibility features. Ideally, a blind person should be able to use the device without encountering any obstacles. Although this characteristic has not been materialized yet, significant progress continues to be made on this issue. Menus are gradually made easier to use, any button that can be pressed, can also be rendered through the voice synthesizer, thus making sure that option is what the user wants, plus many other options which ease the use of the device.


*Fig. 2.13 Mobile devices with accessibility features*

Following the above short description and classification of assistive systems and applications, it becomes obvious that, although some depend on modern technology, and some don't, all follow the same objective, to help people with disabilities become as independent as possible. All these assistive systems and methods help people with different problems to perform certain tasks that have to fulfil, or on which they dependent. Regardless of the type of device or application developed, these will still need to be further improved and enhanced based on feedback from the people who use them, thus making the entire process a rather lengthy one.

# 3 Modern Mobile Applications for Visually Impaired People

## 3.1 Vibro-Tactile Blind User Interaction with Mobile Touchscreens

A blind man can never tell where he presses the screen, because there are no well-structured benchmarks for the individual to realize this. The study from [48], “Vibro-Tactile Enrichment Improves Blind User Interaction with Mobile Touchscreens”, aims to develop these benchmarks, since voice commands are not a suitable solution for everyone (i.e. they cannot be used during meetings, in schools, or due to the various errors which occur when used within noisy spaces). However, it was discovered that certain areas of the brain, which are normally used for vision, might be activated by tactile stimuli.

**Results**

The authors developed a non-invasive software that could help blind people use a touchscreen phone. It was concluded that vibration aids people in imagining a "map" of the phone. Therefore, a mix of audio and vibration had been employed, so that the user was able to tell which areas of the user interface were of interest to him. In the first phase, "land marks" and "region roles" had been employed in order to split Web pages into several pieces, so as to create a logical portioning of the user interface areas. Thus, referencing indications are used as a guide for blind people to steer better and be able to explore cyberspace. It was discovered, however, that there must be a clear separation between logic, design and presentation. In conclusion, an add-on was developed to enrich the user interface, a graphical object whose reaction behavior can be changed. The objective is to offer developers a tool that they can then further modify in order to develop its capacities. Both the messages it transmits and the vibration it emits can be altered. What is important, is that the way in which they can change is very simple, since the XML file is the only one which needs to be modified.

This technique has been applied to two real applications, namely on a dial pad and an email. The purpose was discovering the best locations to place these directives. In the first case, the directives were mere points, positioned to the left of the screen. Following a period of trial, people with visual impairments have determined that the points in question were misleading because, in order to discover the area in which they were positioned on the screen, they had to touch the point precisely, which restricted them to a very narrow perimeter. The result of this finding led to the use of a horizontal band which would be more efficient as, on the one hand, it occupied less space and, on the other hand, it was more easily detectable. It was thus concluded that the most efficient placement of the directives was as follows: in the status bar, in the numeric display (the area visible when the user dials a number), the numeric keypad, the "call" and "delete" buttons, and the navigation bar. Two tests were carried out, following this last implementation.


*Fig. 3.1 Screen Caller [48]*

During the first test, the user had to make a call and then verify the phone number that was written in the numeric display (Fig. 3.1). Several improvements were brought after the completion of the test, namely: if the figure of the numeric keypad is pressed once, this is only read (to verify that the pressed figure is the correct one) and, when pressed twice, the figure is included in the dialed number.

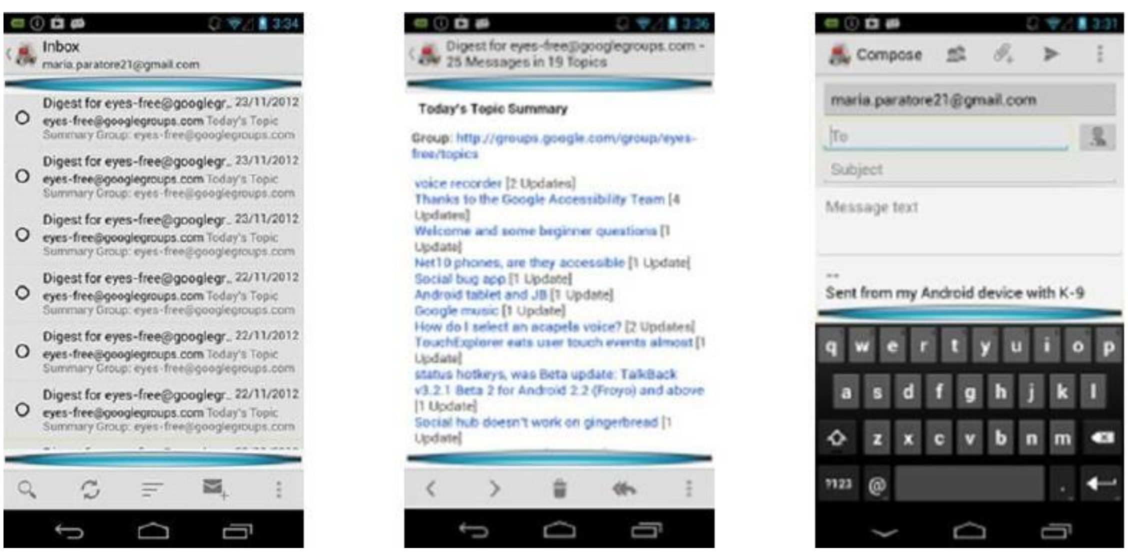

*Fig. 3.2 Email list*

During the second test, the user must browse through a list of received e-mails, read the email body and compose one. The placement of the directives has been made as shown in (Fig. 3.2) as it was the case with the first test, improvements had to be brought to this one as well, namely: to establish a sound which indicates that a field has been selected and that it is ready to be filled in.

**Limitations**

Users who are visually handicapped are not able to browse through content by using the "swipe gestures" module. If a user wishes to modify the text, he has to press the text twice to select the side that he wants to change. Selecting a body of text also brings along its automated reading. However, if the same user wants to insert the new content but then he does not find the correct letters in the first try, he will have to reiterate the reading of the text, as the word selected to be replaced has disappeared. Another defect occurs when a user attempts to read an email. It is impossible for a blind person to detect, in the first try, where the beginning of the text is and, therefore, he will have to press repeatedly until he finds the introduction. This is considered to be frustrating from a visually impaired person’s perspective. Another flaw is that people cannot always use the "audio" because the location does not always allow them to.

## 3.2 Using sonification and corrective verbal feedback to teach touchscreen gesture

It is assumed that people inherently know the gestures needed to use a telephone, but many, however, do not understand how difficult these are when the user had lost his sight. While people with sight learn how to make the signs needed to use a telephone, by means of observation, this process is impossible, however, for people with no sight at all. The authors of the paper [49], “Follow That Sound: Using Sonification and Corrective Verbal Feedback to Teach Touchscreen Gestures”, propose two techniques so that users with visual impairments can learn how to perform these signs. They suggest that a verbal or audible feedback to be generated so that users are able to execute certain gestures on a touchscreen.

**Results**

The first study is entitled “CORRECTIVE FEEDBACK MINUTES”. It analyzes the user's gestures and offers verbal feedback on how to change the gesture so as to make it as similar to the reference gesture as possible. The second study, called “GESTURE SONIFICATION”, aims to generate a sound at the moment when the user touches the screen. Users can then compare the sound generated at that point, to the reference sound, in order to realize if they performed the gesture adequately. Different sounds are used for the *x* and *y* axes of the screen, so that users realize the position of their finger on the screen. The first study involved 12 volunteers with visual impairments, possible forms of audible feedback being tested with their help.

Because the phone model used lacked a tactile edge, a physical separation coverage, of 700x700px in size, had to be created for the appropriate size of the active area solicited by the application. The same coverage also coated the capacitive buttons of the phone so that the risk of the user pressing them was eliminated.

As the users who participated in this study did not lose their sight entirely, the device, along with the user's hands, had to be positioned in a box. In order to determine which the best vocal parameters were, the study was conducted with 4 out of the 12 volunteers.

A variety of audio filter parameters available in the Pure Data library were used. The "pitch" sound was identified as the best one to send the beginning and the end of the area appropriate for a "swipe gesture," but also to transmit the direction.

The process flow of the study was as follows: users could explore the screen by themselves, for 30 seconds, after hearing a feedback sound. After that, they were asked to perform different gestures, following the researcher's instructions (drawing a vertical, horizontal, or diagonal sign, reaching the four corners and the center of the screen, and drawing the requested models).

Following this training period, participants had to complete the following tasks: 16 swipe gestures that varied in direction or length, 16 swipe gestures that varied in direction and speed, 9 screen taps in different areas thereof, 5 forms drawn with different features, and different types of screen taps. A corresponding sound announced participants if they performed the sign correctly, or not.

The positive effects of the stereo sound were exceptionally visible in the case of diagonal and horizontal swipes, which is not surprising because these directions are based on the *x* axis. Participants were able to distinguish between the lengths of the two lines they needed to draw, but also between the two speeds they had to reproduce. In cases where the participants had to touch the screen in different places, the stereo sound proved once again to be the most suitable one. The combination of the stereo sound and pitch was preferred by all participants.

The second study evaluates two feedback techniques: gesture sonification, which uses pitch and stereo sounds (the combination which was the most fruitful one in the first study), and corrective verbal feedback, a technique which employs the text-to-speech technology to automatically analyze the drawn sign. The same device as in the first study was used, with the difference that it needn't be placed in a box again, as volunteers of the second study had lost their sight entirely.

The screen was divided into a 9x9 grid, in which each row was assigned to a different "pitch," and each column was assigned to a different "stereo." Corrective verbal feedback describes, in words, the gesture that the user must do and, after the user performs this gesture, it offers verbal feedback when the gesture was not properly conducted (i.e. it tells the user whether the gesture must be done slower, or quicker, if it needs to be shorter or longer, wider or narrower, if it needs to be done in the opposite direction, above, to the right or to the left, if you must click several times, or fewer times on the screen, and so on). If there are several errors during the making of a gesture, the phone knew how to offer a more complex feedback, such as "above and wider".

Participants had to make 12 swipe gestures (to the left and to the right, long, medium, short, faster and slower), touch screen in 9 different places, do two basic figures (circle and rectangle),along with other figures of different sizes, and touch the screen under different circumstances. After receiving a verbal explanation (e.g. touch the top corner of the screen), this explanation was followed by a sound (study 1corresponding sound).

If the gesture was performed correctly or incorrectly, the feedback was, initially, a corresponding sound, after which users received a verbal feedback. All participants improved the length with which they made the gesture after receiving this verbal feedback. With sound feedback, only half of the participants managed to improve their technique. It was established that users tend to start making a gesture as close to the screen edges as possible.

Both techniques had had a positive feedback on the exercise where participants had to reach different parts of the screen. In cases where the participants were asked to touch the screen in a certain way, there was no error in making a simple touch gesture, in comparison to the double touch gesture (in this case the results were the same for both methods of feedback).

Both feedback methods have helped participants in drawing shapes. Four of the six participants said they preferred the verbal feedback type, one said he preferred both types, and one preferred the sound feedback. Following the completion of a questionnaire, it resulted that many people prefer the verbal feedback. Several persons argued that sounds present at the beginning of each task were helpful.

**Limitations**

In cases in which sound feedback was employed, participants could not distinguish between a short tap and a touch that last longer, during a test in which they had to touch the screen for a certain period of time.

Study number one was conducted only on people who had seeing problems, not on people who had lost their vision completely, although earlier studies show that these tests should be conducted on people who are no longer able to see. People were asked whether they had previously used a touchscreen. It is essential that more people are evaluated in order to draw accurate conclusions.

## 3.3 Ubiquitous awareness tools for blind people

Because some people have completely lost their vision, there are times when they cannot even realize if there are people around them, or not. Thus, a number of mobile device have been developed which, by means of sensors, provide information about the surrounding environment and the people in it. The study described in [50], “Towards ubiquitous awareness tools for blind people”, is intended to help people who have lost their sight learn about everything that surrounds them. A prototype that is able to tell users with complete visual impairment if other people are near them was developed based on multiple studies.

**Results**

This study aims to develop the awareness of users with total visual impairment, in regards to their surroundings, by taking advantage of the already incorporated sensors in mobile devices. Therefore, a prototype was developed, one that can recognize nearby people via Bluetooth. The system adds notes of individuals, notes that are enabled when people are found in the proximity of the user.

In the first phase, a study was conducted with people who have lost vision, in order to realize the limitations and needs they have in the social environment. The study was conducted on 19 people who have completely lost vision. All participants use their mobile phone on a daily basis, and 10 of the 19 have previously used a touchscreen.

Participants complained about the lack of feelings they experience towards not knowing who, or how many people are near them. Although they are aware, in certain circumstances, of the moments in which someone is either entering, or leaving a room, but they can never figure out who it is, unless that person introduces himself. Other participants say they feel uncomfortable in certain locations that are unfamiliar to them, because they cannot approximate the location of certain objects. They specified that, in some cases, they realize what is nearby, by using their hearing, but this becomes an impediment in areas with high noise levels.

The prototype was developed for Android devices. The user interface has been developed so that it can be accessed through gestures. Audio feedback is provided by means of the SVOX Classic TTS. In order to detect nearby people, the device uses the Bluetooth feature. Using the MAC address, which is unique for each device, the application can associate the identifier with any contact that is available in the user's contact list. When the application is in use, this is in a permanent search of other devices found in its vicinity. When another device is detected, the application accesses the database to search if that person to is known the user.

The user can browse through the list of known and unknown devices, he can associate known devices to contacts from his phone and see if anyone was in its proximity. Notifications are sent by means of different vibrations. The application also permits the attachment of notes to contacts. Thus, the user can write a text, or record a message, which is then associated with a contact. Every time a device an attached note is detected, the feedback (vibrations) received by user is different.

The application was tested, and so three participants have used the application in the training center. Another 15 users who have lost their sight were invited to join the study, with their mobile devices' Bluetooth option active and visible. The three participants received explanations about how the application works. The devices that they received functioned on Android 2.3. In order to achieve the best results possible, the contacts of the 15 other participants had been added to 3 volunteers' contact lists. All three users were able to use the application with ease.

Although the 15 contacts were saved in their device, users have been notified and the other devices that were still nearby (people who entered the training center and were active Bluetooth on visible). Following an interrogation session, the three users said they would like to be able to choose the contacts on which to be notified, and on what time of day they receive notifications.

### Limitations

One of the disadvantages this application presents is that it uses Bluetooth to discover nearby phones. Other users also have to enable the Bluetooth option, and set it to be visible, so that their device can be detected via the application. Users have reported that there is some delay in the recognition of another device and this, in turn, leads to delayed notifications. Another user feedback suggests taking into consideration the possibility to set the desired audio mode: silent or meeting.

## 3.4 Haptic guidance on touch surfaces

Nowadays, touchscreens are replacing traditional buttons that have an unpleasant design. However, lack of feedback and tangible guidance can become an impediment for users who have lost their sight. In addition to developing vibration feedback, touch screen use can be improved by structures of "static haptic" type, such as profiled or structured surfaces. The paper [51], “I feel it in my fingers: haptic guidance on touch surfaces”, presents the prototype of an application that proposes interaction by using four fingers, facilitated through touch guidance.

**Results**

In order to create the prototype that combines touch and haptic, a 0.5 mm thick silicon foil was placed on the surface of an Android tablet. The foil is self-adhesive due to the vacuum created between it and the tablet surface. In addition to this, the foil was fixed with adhesive tape on the back of the tablet to prevent slippage occurrence during interaction. In this way they could add two different types of haptic structures. The part of the foil which was cut formed a recessed sharp edge. The other edges are fine and were formed by covering thin rectangles with foil.

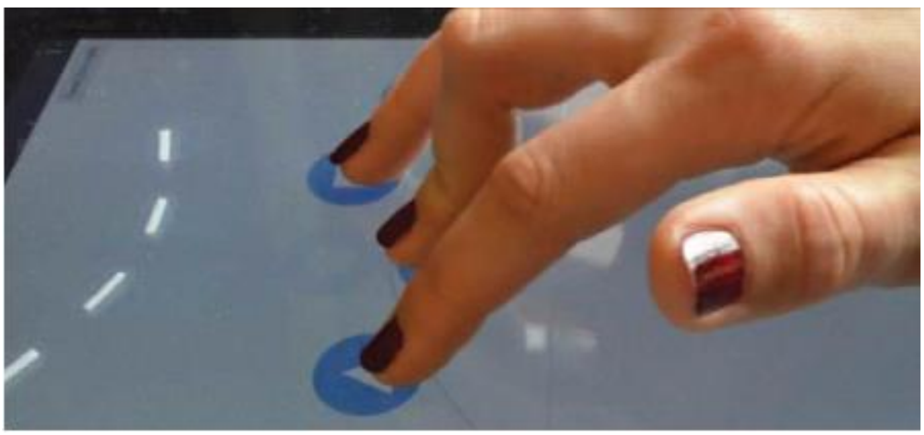

*Fig. 3.3 Fingers position on the touchscreen [51]*

These elements determine the position intended for the user’s fingertips (Fig. 3.3). The prototype has two button positioning options: they can be placed traditionally, in fixed positions, or they can be flexible and adjusted by touch (flexible positioning occurs when the user places his hand on the screen, near or over the haptic type edge, the buttons appear below the 4 finger tips and follow hand as it moves; this technique requires less visual attention as opposed to the buttons being placed in a fixed position). A button can be selected when it is pressed twice consecutively, or it can be pulled vertically downward, over the haptic edge. After the pulling gesture, the finger must return to original position. Both techniques can be implemented by users who have lost their vision, although the pulling downward technique requires a more nuanced feedback, due to the edge.

Thus, the choice was set upon the consecutive tap method, as fewer errors were met in its case. An evaluation of the prototype was made during a study that included 12 volunteers. All volunteers were using or have used touchscreens. An adjustable seat and steering wheel without pedals were fitted for the test. In order to minimize costs, videos with traffic situations were presented on a screen in front of the seat. To get people to pay attention to the driving experience, they had to answer, at the end of the test, a few questions about incidents that occurred along the way.

The tablet was placed to the right of the front seat. Four symbols reminded people about the various functions available. A demonstration before the test showed people how to perform tasks by using four fingers. After this demonstration, the video began on the screen and people were asked to focus on it.

Each prototype was tested for 16 selected symbols shown in random order, while the buttons were equally distributed, each appearing for four times. Symbols that had to be pressed were announced by audio control, and after they were pressed, the user received an audible feedback so that he knew if he had pressed the right button or not.

The time in which the test was performed and the errors that were encountered during this period were registered by an Android application. All the cases in which people looked at the tablet, or when unexpected errors occurred, were noted by an evaluator.

After an evaluation was performed, it resulted that all prototypes are easy to use (including all button placements). The gesture of resting one’s hand on the touchscreen surface was considered more convenient than interacting with a touchscreen which is located vertically. The flexible position, in combination with the "grab" and "double tap" techniques, were considered to be the best choices, as these techniques recorded the fastest time of selection. The flexible position of the buttons registered fewer errors than the fixed one and, in addition, in the case of the flexible position, people did not have the impulse to look at the tablet.

The "drag" option was performed faster than the "double tap", although the opinions of participants were divided in this case. Some participants said the former is more convenient as it does not require the user to lift his finger off the screen, while others said they did not find it to be an intuitive option. Some participants would have preferred a single tap, or a heavier tap. The two edge types could be distinguished, although the test participants preferred the fine edges. However, some people said that they feel constrained by haptic type elements and they had no problem interacting without them. Interacting without an edge offered people the impression of freedom, so that they looked less at the tablet, than in cases where haptic elements were present.

**Limitations**

At the time of the test, using certain fingers led to better results. Thus, all the fingers showed the same results, more or less, in regards to the speed of selection. Nonetheless, using the index and the middle fingers resulted in fewer errors, and have been assessed as being suitable for this activity type, rather than the ring or little finger. For testing purposes, the use of the thumb has been suggested for study integration, due to its flexibility.

## 3.5 A blind-friendly photography application for smartphones

Photography offers the opportunity to capture a moment forever. Because photography is closely linked to visual information, it is extremely difficult for a user who had lost his sight to envision this reality. Because of this, pictures taken by such a user lack a particular subject. Thus, the study described in [52] aims to facilitate independence to a user who has lost his sight, independence in taking a picture, but also in sharing it with others.

**Results**

This study proposes two hypotheses. Firstly, if you add a sound to picture, along with time, date and the location in which it was done, the user will find it easier to retrieve the photos that he seeks. Secondly, people with congenital blindness prefer a linear administration, while people with accidental blindness prefer a hierarchical administration.

The proposed solution encourages testing for both people who have lost vision completely, and for people with visual impairments. The feedback from at least 20 users will be necessary in order to further improve the application.

After the prototype is complete, for further development the entire logic has to be revised and retested on repeated basis until the system allows all test participants to take, organize, and share photos. For this application to be developed, three phases must be followed, so that the application will be accessible to both people with congenital blindness, and people with an accidental blindness.

The intention of the first phase is to help users focus the camera objective and take a picture, at which time they will receive audible feedback. (i.e. center the subject). The second phase aims at the development of a system to help users organize a photo library, and thus teach them how to identify the desired picture, by means of specific directives. The third phase has the purpose of developing a system to assist people while they share photos online. The fourth phase will end with the integration of the first 3 phases within a single application.

After a question & answer session, it was concluded that people who have lost their sight are interested in this type of application, more precisely, in succeeding to take a photo by themselves.

The application developed is still in the prototype stage. It records surrounding sounds, and the user can, in turn, record an audio message. The application takes into account, and saves the time, date and location where the photo was taken.

This data aims to help the user identify the desired pictures. The application was tested with 5 participants. They said they were satisfied that they can locate pictures more quickly, and that they can share them with other users too.

**Limitations**

The problems encountered by people who lost their sight, when they want to take a photo, are as follow: focusing, proper positioning, proper frame selection, improving photo quality, identifying objects that are in the picture, naming photographs, and manipulating photos.

## 3.6 Multimodal Text Input Keypad Touchscreen

The study described in [53] aims at sharing experiences that people with total blindness have to face when they want to write a text on a mobile device that uses a touch screen display type.

To better understand the problems faced by these users, a text input method called Multimodal Text Input Keypad Touchscreen (MTITK) was developed and tested. This method is a prototype for audio-tactile text input, based on multiple taps which is also based on the phone's keypad, as it is arranged in several components. Every part contains five characters, each with different audio-tactile feedback.

Users need to explore the screen to identify the currently selected character, to press on the screen in order to enter a text body, and make a particular gesture to alter the written text. Throughout this entire time, they will receive corresponding feedback: audio, voice or tactile. The prototype was implemented for Android.

**Results**

There were three approaches presented to manage the introduction of characters on a touch screen device without this activity soliciting the user's visual ability, whatsoever.

The first approach, called Multitouch Character Encoding, is based on the characters encoded form and focuses on the number of fingers the user has, at the time, on the screen.

The best known method of this type is called Braille, a method in which a rectangular cell, containing six points of binary ranking, offers 64 possible patterns. For example, BrailleTouch is a text input method that can be used on mobile devices, by using both hands. A non-braille example, is called DidiTaps and uses a coding based on four minimal gestures and audio feedback. Although, overall, people who are blind know Braille, they do not trust using it to write, or to read.

A second approach, called Character Drawing, aims at drawing some characters directly on the screen by employing the user's finger, or a stylus.

A third method is called Constructive Methods. In this type of method, users perform different actions in order to insert a character. The "multitap" option is the most famous example in regards to mobile devices. The idea of designing MTITK (Fig. 3.4) began with the development a user interface which included haptic elements, thus generating haptic feedback by using only the engine integrated into the mobile device.

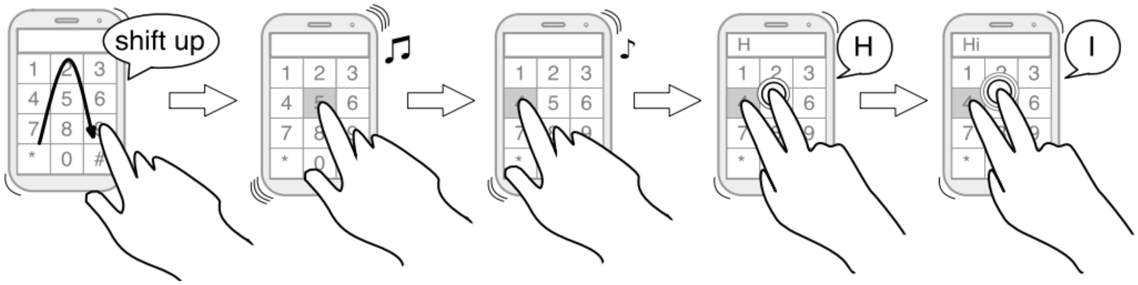


*Fig. 3.4 An example of how a user can enter the word "HI" in MTITK [53]*

The general MTITK plan is a common one, namely: it is based on the 12 buttons (a 4x3 grid), generally integrated into any phone (Fig. 3.5). This plan is defined by the International Telecommunications Union, and it is recommended by the International Organization for Standardization (International Organization for Standardization).

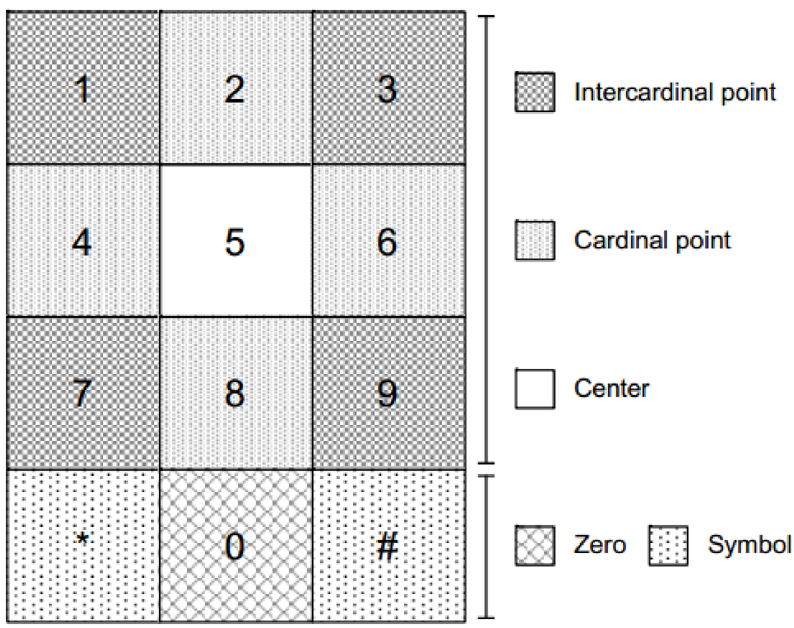


*Fig. 3.5 Keypad Layout and key groups [53]*

The keys were divided into 5 groups, namely, each having a different audio-tactile feedback so that the user can identify what key he pressed accordingly to the provided feedback. In the first phase, the keys were divided into two categories: the first category contained numbers (from 1 to 9), and the second category contained keys on the bottom row (the asterisk, the hash character, and the number 0).

The keys are further divided into subcategories. These sections divide keys based on the characteristics of the cardinal points (the two, four, six and eight characters), on those that are not cardinal points (keys one, three, seven, and nine), and finally on centrality (the five key). The last line is divided into two subcategories: the zero key forms a sub-category and two keys that contain signs (the asterisk and the hash keys) form another subset. Two adjacent keys do not provide the same sound feedback.

At the time when the study was written, keyboards included characters only for the following languages: English, French, Italian and Spanish. All letters had been allocated to the two and nine keys. Characters specific to a certain language had been assigned to the one, asterisk, hash, and zero keys. To insert a new row, the user had to perform a particular gesture.

The option to "shift" was also available, whose status could have been in two states: up or down. Thus, if the key status was down, the characters were written with small letters and a set of special characters would appear. If not, the letters would have been capitalized, and another set of special characters made available. The space key option, along with numeric characters, could be selected by pressing an equal number of two statuses of the Shift key.

The insertion of characters is a process that takes place in two stages. In the first phase, the user explores the keyboard with one finger, while receiving audio-tactile feedback based on the keys he touches (i.e. the key that is active). Once the desired key is active, without lifting his finger and without changing the active key, the user must press the screen as many times as necessary to select the desired character.

Finally, the device will read the character introduced by means of TTS, and a short vibration will confirm the introduction of this character. Through simple, continuous taps, performed on the user interface, the user will be allowed the option of altering the text, and he will be able to insert a new row, or to activate a command such as: seeking or send. If a gesture performed by the user is recognized by the device, he will be notified by a vibration, but also by an audible feedback (i.e. the text has been deleted).

Thus, a gesture to the left deletes the last character entered, a gesture to the left and then one up erases the last word introduced, a gesture to the left and then one down erases the last sentence, and gesture to the left and then one down and one to the right leads to the emptying of the entire field dedicated to text. To test the MTITK, a prototype was created and implemented on an Android device which had the 4.2.x version, this being the minimum required one. For sound synthesis, Google TTS was used. During the tests, three Android phones were used: Galaxy Nexus, Nexus 4 and Nexus 5. To identify gestures, the Android Gesture package was employed.

| Task | VE | EA | NE | DI | VD | DK |
|---|---|---|---|---|---|---|
| Identify keys | 4 | 5 | 1 | 1 | 1 | 2 |
| Autocomplete | 1 | 1 | 4 | 1 | 0 | 7 |
| Delete last character | 5 | 5 | 2 | 0 | 0 | 2 |
| Delete one or more words | 2 | 1 | 0 | 5 | 4 | 2 |
| Place the cursor | 1 | 2 | 2 | 4 | 3 | 2 |
| Select text | 1 | 0 | 0 | 2 | 2 | 9 |
| Read inserted text | 6 | 4 | 1 | 1 | 0 | 2 |

*Fig. 3.6 Number of participants by self-reported difficulty level on text entry and editing tasks on the QWERTY virtual keyboard. Scale: VE (Very easy), EA (Easy), NE (Neutral), DI (Difficult), VD (Very difficult) and DK (I don't know) [53]*

Two users, a man and a woman, both with total visual impairment, attended the testing. They expressed their opinion about the application while they were using it. In the first phase, the purpose of this application and usage methods were detailed for them. Users had been handed a phone (Galaxy Nexus and Nexus 4) and were asked to explore the application by themselves. Once the application became familiar to them, participants were asked to perform certain tasks (write in capital letters, read the last character introduced, or delete the last word entered) (Fig. 3.6), simulating both a quiet and a noisy environment (three people were asked to hold a discussion around them). Both participants were able to successfully use the application.

It was observed that the participant who handled the phone that had physical keys, managed to retain the order of the characters better. Both participants managed to hold the phone in one hand only, while using the other hand to insert the text.

In the first phase, the participants used their index finger to explore the keypad, and their middle finger to confirm the desired character. Later they began to use the middle finger too for exploration purposes, and the index, or ring finger to tap on the screen (for confirmation). After this first test was conducted, the text input and the feedback synchronization methods were both developed.

Another test was conducted, this time comprising 14 participants. Some of them had very reduced visual capacity, while the rest had lost their sight entirely. Most participants have used touchscreen phones before, and almost all said they remembered the location of the 12 buttons.

During this test, three Nexus 5 with Android 4.4 (4.95 inch screen, 130g) phones were used, all of them with only three physical buttons: the power button and two volume buttons. There was no edge used to delineate the screen. The audio feedback was rendered by Google Voice TTS, the Italian language pack.

In the first phase, participants were asked to explore the application by themselves. In the next phase, users were asked to perform three tasks: to write a four-letter word, write a word with all the vowels, and insert a phone number. The tasks were accompanied by audio, tactile and haptic feedback. Both a quiet and a noisy environment were simulated.

All participants preferred the variant in which they were given both audio and haptic feedback. Participants considered inserting a phone number as the most useful element, as the task could be performed with ease in a noisy environment, from their point of view, as the vibration pattern is easily recognizable. It's preferable to use Android rather than iOS, because the former allows software development on multiple platforms, in addition to having less costly devices. Users who have previously used a touchscreen device, find the application very easy to understand and use.

**Limitations**

When users found themselves in a noisy environment, they had difficulties to correctly identify the keys by using the haptic feedback type. Some users had difficulties in retaining the necessary gestures to edit the text. The moment they had to introduce a text, participants instinctively raised their finger from the screen, as they were accustomed to such a move, from a normal keyboard. The users also had difficulties to achieve gestures that contained sharp angles, or 90 degrees angles.

## 3.7 Gesture and exploration based on touchscreen keyboards for the blind

The paper “Objective comparison between gesture and exploration based on touchscreen keyboards for the blind” [54] reports the results of an experimental study conducted on people with total visual disability, which were evaluated on their performances of writing individual posts by using two different writing techniques.

BrailleTouch is a writing technique that requires the use of gestures and the stock Android keyboard is a second keyboard, which requires tactile exploration in order to write. The study shows that the BrailleTouch technique was two times more efficient than the stock Android keyboard, in regards to writing each character.

**Results**

People with total visual impairment are not able capable of using a touchscreen phone because of the lack of tactile directives, which might help them navigate the streets or write. BrailleTouch is a technique used incorporated in smart phones with the multi-touch option. What makes this technique special is that it does not involve the use of sight.


*Fig. 3.7 Placing fingers example [54]*

The key aspect regarding this technology is that it has fewer buttons than a user has fingers. However, the user should not move his fingers to find the right combination to write. Once placed, the fingers remain in the same position. (Fig. 3.7) This is crucial for users who have lost their sight. The six buttons used correspond spatially with the mental map of the six cells of a Braille character, along with the placements of the six fingers which will be employed.

When the user is typing, the device will generate an audio feedback. The user will use both hands to keep the device with the back of the screen towards him. One finger will be placed on each button. The TalkBack Android keyboard is used through exploration. Thus, the user will click on different characters and receive audio feedback about which character was pressed. When lifting a finger off the last pressed character, it will be considered as the one wanted by the user. Each pressing of the "space" button automatically leads to a vocalization of the last word written. The keyboard occupies approximately 1/3 of the screen and it is located at the bottom part.

The study involved four people with total visual disability. They were all familiar with the QWERTY keyboard, but also with audio feedback received when they were writing. Each participant had a previous education of at least 10 years about the Braille alphabet. However, few of them have used the alphabet to write during the recent past period.

For this study, Samsung Galaxy Nexus (Android 4.2.2 Jelly Bean version) phones were used. To test the Android keyboard, the portrait orientation was employed, while the landscape orientation was used to test BrailleTouch keyboard (it was made exclusively for landscape orientation).

Firstly, the participants were explained how the new system functioned and which were the signs / gestures necessary for them to succeed in writing a text. The feedback directives were also explained, so that they could realize if what they wrote corresponded with their intentions.

In the next phase, users were allowed to explore the application without being constrained by time. However, the data they had entered was taken into account, so that an assessment could be made regarding the speed at which a user learnt to use such an application. After this phase of practice, users had to write a specific sentence, without being constrained by time, because it was more important to carry out the task, rather than to leave it incomplete. The sentence did not contain numbers, or words that required capitalization or punctuation.

Participants received assistance for spelling whenever needed, because for them English is considered to be a secondary language. The experiment was repeated, and users asked to introduce a sentence, each time using a different text input system.

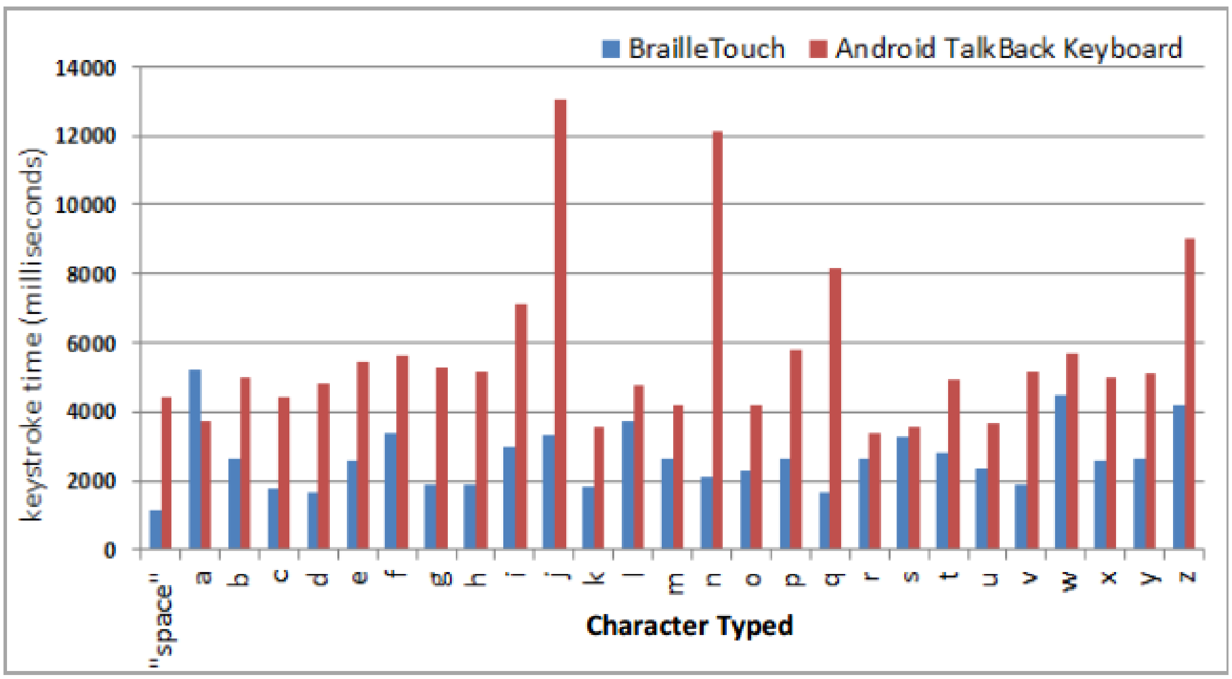


*Fig. 3.8 Keystroke time – Speed [54]*

At the end of each experiment, results were collected from all of the participants. The data thus gathered was analyzed to determine the speed (Fig. 3.8) and accuracy (Fig. 3.9) with which each participant worked. Each participant was able to type, on average, 3.91 words per minute, using the BrailleTouch keyboard, while they managed to type only 2.17 wpm by using the Android keyboard. The timeframe needed to press the letter "h" was recorded to be 3530 milliseconds. This time does not include the error (the time required to find that key). Therefore, by adding the error time too, a timeframe of 9910 milliseconds is obtained, comprising all the keys that the user had to press to finally reach the correct key.

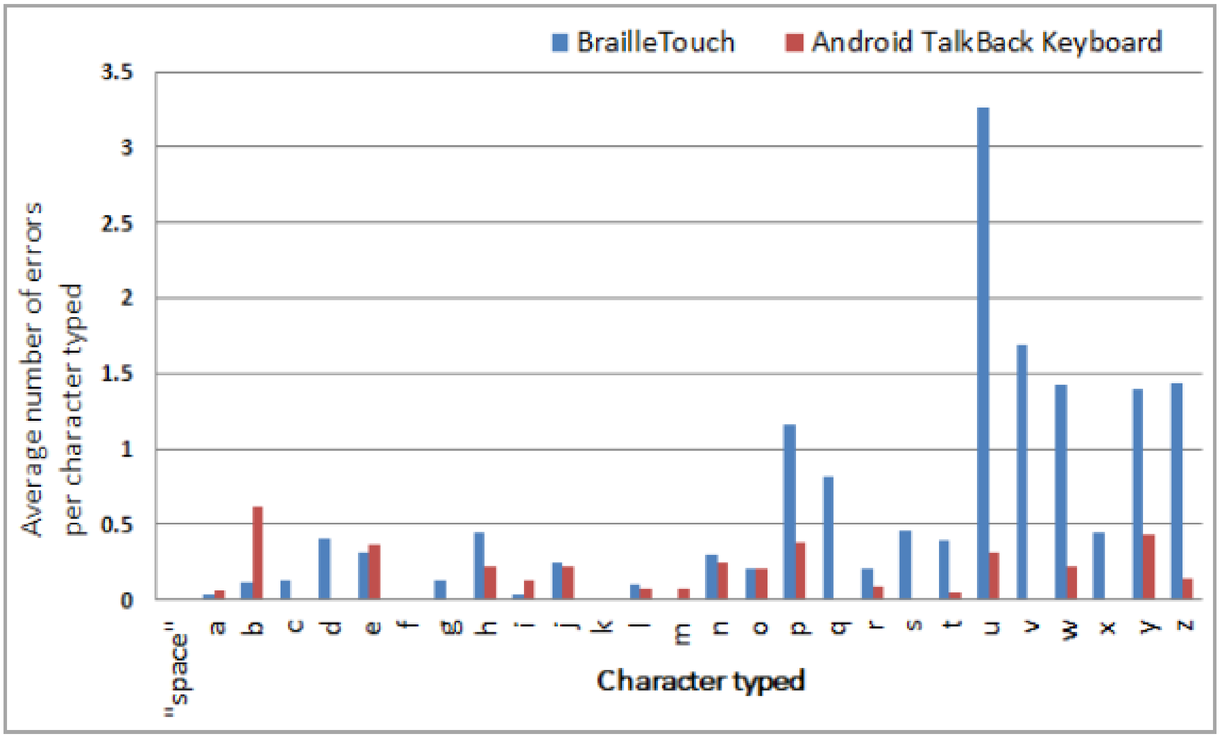


*Fig. 3.9 Average error- accuracy [54]*

Having analyzed the two writing techniques, it was concluded that the use of the BrailleTouch keyboard led to a quicker text input. By studying the number of mistakes, however, it was concluded that the use of the BrailleTouch led to the making of almost the same number of mistakes, as when the Android keyboard was used, where characters did not require the use of point 3 or point 6. An increase in the number of points is directly proportional to an increase in the number of errors. The BrailleTouch keyboard's accuracy decreases when entering characters which require the use of four, or more points. While typing characters like "v", "w", "y", "z" is performed with 1.5 errors / character, typing a vowel / semivowel, such as "u", resulted in three errors / keystroke. These errors may be due to the fact that test participants had worse motor control over the ring finger (*digitusmedicinalis*), which is used to press points 3 and 6 on the BrailleTouch keyboard.

It can thus be concluded that the QWERTY keypad for Android (which uses the TalkBack technique) is more precise and time-saving, in comparison to the BrailleTouch, where the number of points is very high for a second keyboard. Despite this, errors may decrease in frequency, if the experience in using the BrailleTouch keyboard increases. All participants preferred the British accent of a man, against that of a woman from the US (the accent used by Google Text-to-Speech).

**Limitations**

If the case of the Android keyboard, participants believed that the "Backspace" key is very difficult to locate. The required finger placement on the BrailleTouch keyboard was difficult to maintain, according to participants. Users have suggested that both keyboards need a more powerful editing tool so that they would be able to return easily and correct misspelled words. All users agreed that they would have entered characters during a shorter period of time if they were assigned a time frame (about a month), in which they could have used the BrailleTouch keyboard regularly. BrailleTouch keyboard requires longer time for accommodation than the QWERTY Android keyboard. As the number of Braille points increases, the keyboard accuracy decreases and the number of fingers required to enter a character increases, respectively.

## 3.8 Tactons– Structured tactile messages for the blind

Montagu [64] has proven that the surface of the human body covered by skin is approximately 2 square meters, being full of receptors. Van Erp [65] reached the conclusion that we do not use our skin’s sensory capacity nearly enough, although the technology based on touchscreen devices has developed significantly recently. The skin’s sensory capacity is as complex as hearing or sight, therefore it should be treated as an efficient channel of communication with technology. The researchers have not yet placed great emphasis on this aspect – they have developed prototypes only for very strict or specific applications, not trying to develop large scale consumption devices.

The tactile sense has been divided into two broad categories: dermal and kinesthetic. The kinesthetic sense is based on muscle movement which can be observed physically, while the dermal sense is based on skin receptors, which detect the sensation of vibration, temperature or pain. At present, tactile technology takes into account the dermic sense.

One of the technologies [66] which use the skin’s capacity to feel vibrations is the vibrotactile actuator. It uses vibrations on a frequency ranging from 10 to 500 Hz, being made up of a matrix of metallic pins, capable of vibrating independently. This technology was incorporated into the VitTouch mouse, for example, where the three buttons were covered in matrixes capable of vibrating and of stimulation the fingertips.

These actuators have often been used to enable the blind to read texts – this way they can use the pin matrix to turn writing into Braille alphabet. Kurze [67] demonstrated that the tactile sense can also be used to create graphic representations of images or objects.

The term tacton was arrived at after research conducted into various ways of interacting through vibrations. The tacton is a structured abstract message which can transmit complex information without the need for visual representation. A conclusion was reached that the interaction with computer systems can be improved and that we can recreate objects in the virtual environment as closely as possible to the reality, such as reproducing the texture of materials by haptic devices.

The tacton is created by encoding information using several parameters such as frequency, amplitude, wave shape, duration, rhythm and location of vibration on the human body the frequency we can perceive ranges from 20 to 1,000 Hz, but our maximum sensitivity is 250 Hz. It is yet not known how many different frequencies a person can perceive, but Gill suggested the use of a maximum of 9 levels. It is recommended that the amplitude should be up to 28dB, as beyond this level the perception becomes deteriorated. Gunther [68] also mentioned that no more than 4 different levels of amplitude should be used, although a person is capable of distinguishing many more. In the case of the wave shape parameter, a person can detect the sine and square waves, the rest being harder to distinguish.

As concerns the signal duration, Gunther [56] demonstrated that a short duration is felt by the subject as a tap, while a longer duration is perceived as if something was rising up out of the skin. The location where the sensors are situated is also important, as different parts of the body have a different sensitivity. By combining all these parameters through tactons varied information can be transmitted to the subjects. Although fingers are usually used to feel the vibrations, researchers have trained subjects to recognize certain patterns on their back or on their abdomen, in order to be able to use their fingers for another activity simultaneously. Once the message is encoded (because the tacton is an abstract message) the person who will use this "language" will have to learn the association of every tacton with its meaning.

Tactons can be used both by the visually impaired and by the people who have no disability. For example, if we look at a monitor full of information we cannot pay equal attention to two things simultaneously or to tow events happening on opposed points on the screen. But if we were paying attention to one of them and the second were transmitted to us through a tacton we would not miss any information.

Tactons have also managed to provide the blind with information referring to graphic elements, thus reducing the existing differences between the perception of people with normal sight and that of people with visual impairment. Through the use of haptic devices, scientists have managed to represent graphically all this information in a non-visual way.

One of the most important fields in which tactons can be used are mobile devices. Mobile phones and tablets are based on visual elements and touchscreens. Touchscreens generally react to touch (with a fingertip or with a touchscreen stylus) although the screen would be able to provide many more sensations. In the case of portable devices vibration areas such as belts could be set up on the body to indicate the navigation direction.

## 3.9 Conclusions

Most of the solutions presented in this chapter [55] are still in concept phase or are continuously developing due to the necessity of more efficacious functionality. The fact that there are very few working applications launched worldwide proves that the research area is still unripe and not fully explored.

The most important aspect noticed is that although the research on human tactile capabilities is already well-established [65] most of the applications taken into account do not focus efficiently on constructing complex feedback based on vibrations, offering mostly audio feedback. We believe that this is a notable result that can guide us in further research on exploiting new methods of approach by using to a great extent our tactile capabilities where sound alone seems to be sometimes inefficient.

A significant problem is that at present all the applications and concepts in this area are based on native text-to-speech generators met/seen on the platforms of operating systems. These generators are only available in a limited number of languages for now, Romanian not being on that list.

This synthesis together with the solutions for improvement resulting from testing and analysis sessions was extremely useful as a starting point for the entire research, both in the area of mobile devices and for the development of assistive systems for the blind.

# 4 Developed touchscreen based applications for visually impaired people

## 4.1 Description

The last months of 2008 brought along the launch of the first Android smartphone. From that moment forth, mobile devices have been enlisted in a continual development trajectory. They are part of people's everyday activities and, on a global scale, there already are as many as 1.7 billion smartphone utilizers. Given the fact that the development environment for Android applications is free of charge and has a lot of necessary modern programming tools and utilities, I decided to focus on developing touchscreen applications using the Android platform.

Since there is a considerable number of people worldwide who suffer from seeing deficiencies, I hope that the application described in this chapter will complement the modernization of the learning process, and enhance future utilization of mobile devices. The learning process commences with menu processing and a rendering of the actions encompassed by the application, followed by a study of the basic geometric shapes. The entire coordination of the process will be made by relying on tactile and audible feedback which is sent to the user, through the mobile device.

From a scientific point of view, as the previous chapter (3) highlights, there are some important research papers regarding this subject area from witch I have learned a lot in the process of building touchscreen based applications for visually impaired people.

If we were to look towards a more tangible end-user product, the most important one to study is the development and usability of GeorgiPhone [84]. "GeorgiePhone is a family of apps for blind or low vision people and people looking for a simple, no nonsense phone. With its big talking buttons, clear print, simple layout [73] and choice of color themes, it is far more than a screenreader for smartphones."

In the following pages, I will describe the development stages, logic and remarks related to an application for visually impaired people. This applications contains a series of tools emerged from the ideas assimilated during personal experience and experiments (chapter 7) combined with the knowledge obtained from research articles and end-user accessibility smartphone applications.

The activities and scenarios implemented are not end-user applications for themselves, instead, they are meant to achieve key purposes:

- people with eye sight problems will get familiar with touchscreen devices and gain trust in using them
- researchers get a chance to study how visually impaired people are adapting to new technologies

- developers will learn how to design and implement new accessibility interfaces and tools adapted to special needs and purposes

Users will learn basic geometric shapes, piano singing and menu navigation. After a period of exercises and perseverance they will be able to imagine how these really look on a touchscreen surface. People who are not confronted by eyesight problems whatsoever find it difficult to understand that those with no eyesight at all cannot even imagine what a square, or a circle, looks like. However, given the fact that blind people have never seen a straight line or a curve, being able to envision such a shape using technology is great step forward.

The proposed set of tools allows the user, through speech synthesis engines, to receive continuous audible feedback from the device. This synthesizer can be implemented for a large number of languages. This early version includes English and Romanian. With the help of the same synthesizer, the user will hear what types of buttons he pressed, in which kind of activities he’s engaged, and receive assistance for certain actions. Thus the user, aided by the device, is practically assisted along the entire learning process.

The system also provides tactile feedback via the vibration motor every Android device currently on the market has incorporated. Through vibrations, the user will know the number of the button he had just pressed, but also when he reached the outline of the shape that is to be learned. This feature is important within the application as it can be used in environments with high noise levels. In cases when the user is familiar with what the application is about, and what he is supposed to do, he can then coordinate himself only based on vibration, as it is no longer necessary to listen to instructions.

The entire learning process is designed both for completely blind persons, but also for people with serious sight deficiencies. With consideration for those who can only grasp the differences between light and dark, or maybe colors, the entire application has a special logic for the user interface in order to create to high contrasts. The menu buttons alternate between black and white, the white geometrical figures are drawn onto a black background with red borders, the notifications screens are red.

Code snippets and technical implementation details can be found in [A1].

## 4.2 Activities

### 4.2.1 Language Activity

The language activity is just a white screen with no user interface items. The application always opens this activity first, so that the user can choose the language before anything else.

After getting here, as a feedback, the application will output throw the text-to-speech engine the following guiding text:

*Hello, welcome to the touchscreen application for visually impaired people. For English make a single tap on the screen.*

*Bună ziua, bun venit în aplicația pe ecran tactil pentru persoanele cu deficiențe de vedere. Pentru limba Romană, atingeti ecranul scurt de doua ori.*

Depending on the chosen language, messages and buttons will be translated and the audio feedback will also have the selected language. Currently the application has two languages available: Romanian and English. The user can select English with one tap and Romanian with two taps. For every action basically a gesture is waited and a global entity is set according to the chosen language.

### 4.2.2 Main Menu

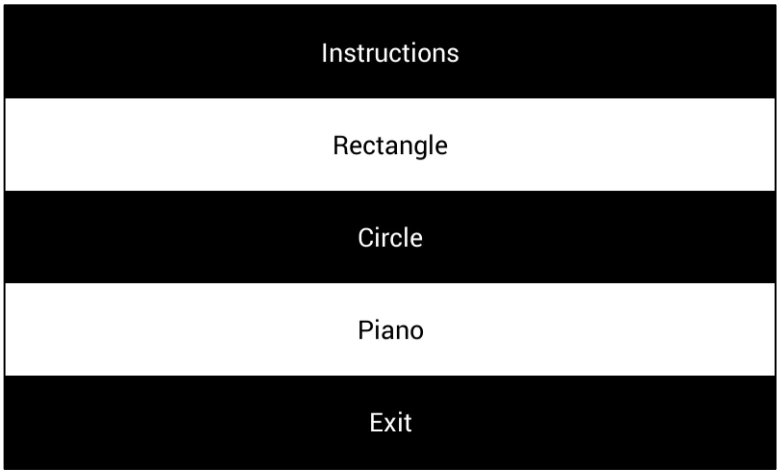


*Fig. 4.1. Main Menu*

The first important screen that comes to the attention of the user is the main menu (Fig. 4.1), from here he can navigate to all other features.

After getting here, as a feedback, the application will output throw the text-to-speech engine the following guiding text: *Search the activity you want through the buttons and long press on it for entering. Please begin with instructions. The menu has 5 buttons, each one vibrating with the same number as the position. All buttons are as wide as the screen and positioned one below the other. Long press now, for closing help*.

This activity contains the main menu buttons. The application guides the user to choose the desired activity and to long click the corresponding button to continue. At the touch of a button, the application reads the text on the button that was selected, notifying what activity was chosen.

First there is a check for which button was pressed. Then the button text is retrieved, and depending on the chosen language the message for the synthesizer will have the correct language. The device will then vibrate the same number of times as the position of the button in the menu.

To enter the desired activity (tool) after listening to the message of the button, the user needs to press and hold that button (a long press). When this gesture is performed the synthesizer will playback the message corresponding to the newly selected activity for example: *You entered the piano activity*.

When the exit button is long clicked for the first time, a counter will be incremented and the user will be asked if he really wants to exit. If this button is accidentally pressed, the application will continue to run. If the user does, however, wish to exit, he must long press the button once more in order to confirm. In this case, the application is closed.

### 4.2.3 Difficulty selector

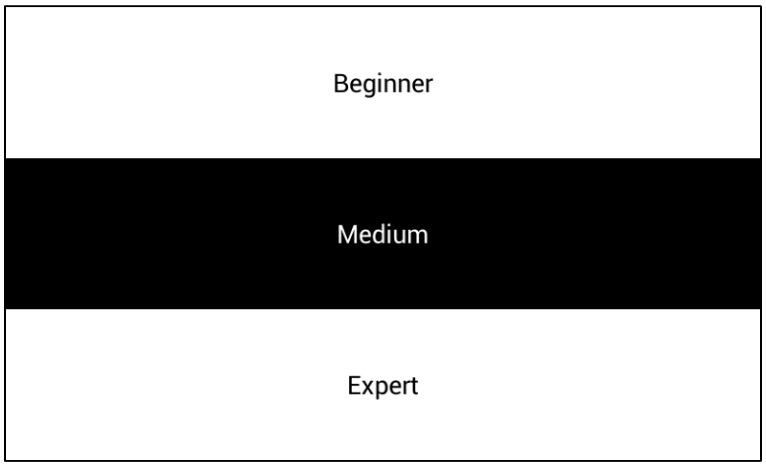


*Fig. 4.2 Difficulty selector*

Every time the user enters an activity, the difficulty selector (Fig. 4.2) is displayed. For each activity there is a separate difficulty selector. After getting here, as a feedback, the application will output throw the text-to-speech engine the following guiding text: *Choose the level you want for learning how to draw a rectangle. The menu has 3 buttons, each one vibrating with the same number as the position. All buttons are as wide as the screen and positioned one below the other. Long press now, for closing help.*

Difficulty selectors for shapes include three buttons: beginner, intermediate and expert. They represent the level of difficulty that the visually impaired person sets for learning stages. When choosing a beginner level, the contour of the geometrical shape will be wider, making it easier to follow. When choosing a more difficult level, the outline will shrink, and more training will be required in order to complete the activity. The configuration activities for geometrical shapes are almost identical and the piano difficulty selector is for displaying an easier keyboard or a full piano keyboard.

### 4.2.4 Notification screen


*Fig. 4.3 Help button and notification screen*

The application was programmed so that at the beginning of each activity there will be a HELP button as large as the screen. This button will encourage the user to listen to the instructions. The device must be held all time in landscape mode, if not, pressing the HELP button will tell the user to turn it in the landscape mode.  The HELP button (Fig. 4.3) can be observed together with the message that the device is held properly. By tapping the screen, the user will hear what to do in the activity. To close the HELP button the user must do a long press action on the screen. Of course, this screen would be useless if the user would just touch by accident the screen during the instructions, which is why this one is a forced screen. Without listening the entire notification message no other activity can be started.

A few text-to-speech guiding text examples for this type of activity:

- *Turn the device in landscape! / You are holding the device correct!*
- *You closed help.*
- *This is not a single tap / You made a single tap.*
- *To move on, long press on the screen and after that, touch it with on finger!*
- *To move on, long press on the screen and after that, do a fling from the left part of the screen to the upper right part of the screen!*

### 4.2.5 Help and Learning

For learning basic gestures on a touch screen device, three activities were implemented. When the user selects in the main menu the "Instructions" activity, he will need to go through all three learning activities that follow in order to learn gestures, without skipping any of them. All activities will start with the screen covered by the specific button for listening the steps to be made. After playing the instructions, the application will display a simple white screen on which the user has to perform the required gesture. All the gestures used by the system are automatically recognized by the device. Some alterations were made where it was required. The three gestures handled by the application are:

- A single tap

In this first activity, the user must touch the screen once. This is the gesture that will launch the *onClick* event for any button in the application. If another gesture is made, the user will be notified of the wrong gesture using the language that was selected when the application started.

If the user has made the gesture correctly, he will be sent to the next learning activity. The device will notify the user that the correct gesture has been performed. Long press it is considerd a longer single tap.

- A double tap

In the second activity, the user must learn how to perform the double tap gesture. For Android devices, upon activation of the accessibility utility, blind people must know how to perform double tapping. This gesture is used to confirm clicking on an item. With just one touch, the synthesizer will playback the text of an item. As in the previous activity, the user will be notified if he makes an error, or if he performs the gesture properly, in which case he will be taken to the next learning activity. It is required to override the predefined gesture in Android systems so that the synthesizer can deliver the corresponding message and then start the next activity.

- The back gesture

In the third gesture learning activity, the user must learn the "Back" gesture. Given that the hardware "Back" button has been disabled, a software replacement is required in order to allow the user to return to a previous action. The difference compared to the standard "Back" button is that the user will not be sent to the last activity he was in, but he will always be sent to the main menu. An exception is when the user is already in the main menu, at which time performing the "Back" gesture will take the user back to choosing the language of application.

To perform the "Back" gesture, the user needs to swipe his finger on the screen from the bottom left corner to the top right corner. The technical details are described below.

The received parameters are:

- event1 – the start of the movement, when the screen is touched
- event2 – the event that generated the onFling gesture
- velocityX - X axis movement speed, measured in pixels / second
- velocityY - Y axis movement speed, measured in pixels / second

If the speed and distance condition is fulfilled, the synthesizer is stopped from playing any message, and the required activity is opened. Meanwhile, the stack of activities is emptied.

### 4.2.6 Rectangle Tool

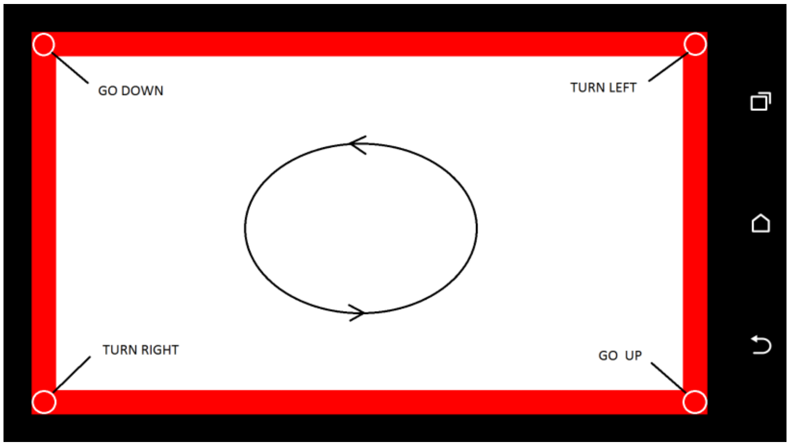


*Fig 4.4 Rectangle Activity*

In Fig. 4.4 there is the rectangle activity. After getting here, as a feedback, the application will output throw the text-to-speech engine the following guiding text: *You entered rectangle activity. To listen to the instructions touch the screen. Find near the margins of the screen the vibrating line. Following it counter clockwise, you will learn how to draw a rectangle. Long press now, for closing help.*

The chosen level in this picture is beginner, so that the vibrating outline will be wider and easier to touch. The user is guided by the HELP option to find the vibrating line and to follow it counterclockwise. Touching the line will make the device vibrate. Once the user touches the inner section of the rectangle, the vibration will stop, so that the user knows he made a mistake and he must find his way back to the vibrating outline of the rectangle.

If the shape is drawn correctly, each time a corner is touched, the device will indicate the next direction the user must follow. A feedback will be given when the user completes the entire shape.

Working with this tool is fascinating because it is the first one from the set and offers an unmatched experience. The skill developed in the process of following the vibrating line will contribute massively to the overall experience.

### 4.2.7 Circle Tool

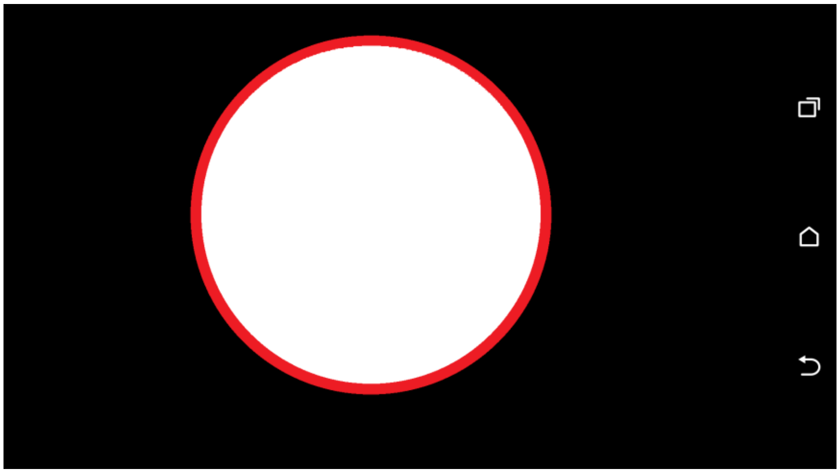

*Fig. 4.5 Circle activity*

The circle tool (Fig. 4.5) helps the user to understand and practice how a circle looks like. After getting here, as a feedback, the application will output throw the text-to-speech engine the following guiding text: *You entered circle activity. To listen to the instructions touch the screen Find on the screen the vibrating line. Following it clockwise, you will learn how a circle looks like. Long press now, for closing help.*

The vibrating line in this example (medium level difficulty) will be smaller, being harder for the user to follow it. This means he already knows how a circle looks like, but needs to practice. Best practice would be to follow this line until perfecting the technique.

After learning the straight paths and logic for the rectangle every users is initially mesmerized when encounters this tool. That is why it is recommended to wait at least 4-5 minutes until switching between geometrical shapes activates. The circle tool is considered harder than the rectangle activity because it does not have guiding corners and directions and because of the precise touching angles that user needs to predict in order to be able to follow the vibrating line continuously.

### 4.2.8 Piano Tool

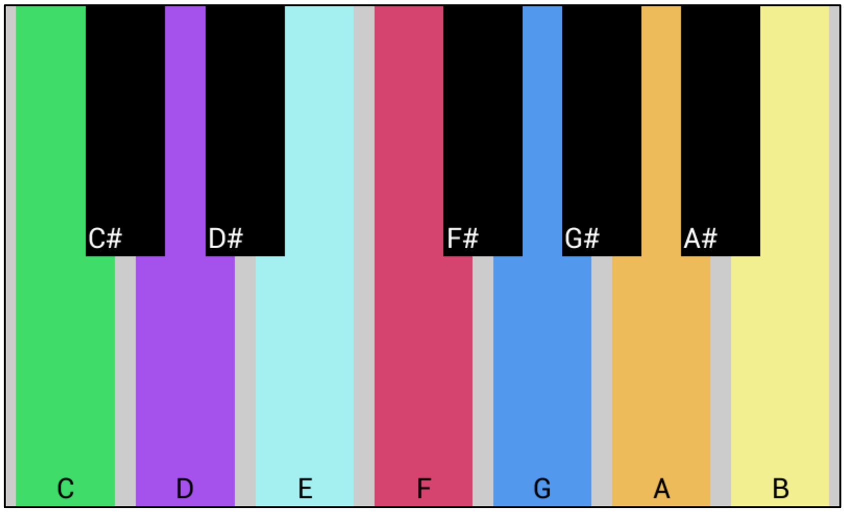


*Fig. 4.6 Piano tool*

The most interesting tool from all the features offered by this experimental application is the piano tool (Fig. 4.6) that helps the user concentrate on the touchscreen in order to be able to sing on a piano simulator. After getting here, as a feedback, the application will output throw the text-to-speech engine the following guiding text: *On the screen is drawn the first octave of a piano. Each note vibrate differently, has a unique musical sound. Between two notes there is a white non-vibrating space. Good luck musician. Touch to sing! Long press now, for closing help.*

This activity was created with the purpose of teaching visually impaired persons to coordinate their actions better on a touch screen device. After training with the piano, they know how to press a required key without going through all of them. Each key has the original sound of the corresponding piano note and also vibrates differently from the rest of the keys. The keys are implemented using a list of buttons. Black keys are each comprised of two buttons close to each other, in order to better simulate the design of a real piano.

The keys were colored so that two adjacent flaps have high contrast between each other, and are easily distinguishable. The short black keys are also easy to find. If the user can distinguish only between black and white, he will not be able to see the colors, in this case, feedback will be based on vibrations when passing from one key to another, and also on the sound that the keys produce when touched.

In terms of difficulty, in comparison with the circle and the rectangle, the piano is way harder to master. The piano has a complex logic that outputs 12 different vibration types, one for each piano note.

#### 4.2.9 Supervisor tool

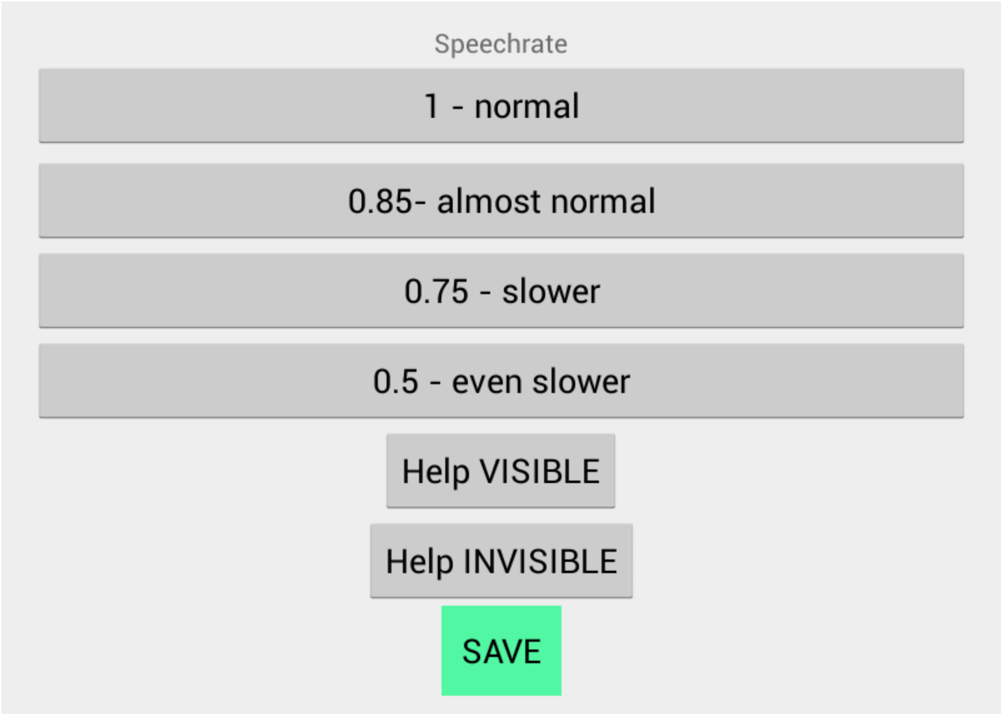


*Fig 4.7 Supervisor option*

This is a special screen (Fig. 4.7), which can be launched only before reaching the start menu, it was designed for supervisors. This activity can only be accessed after opening the application by performing the back gesture in the language selection activity.

In this activity the supervisor can set the speed of the speech synthesizer and whether or not to render the help buttons. These settings are then used throughout the entire application. If the speech synthesis speed changes, the change affects all activities in the application. The standard speed of speech is 1. If desired, a lower speech rate can be set for the speech synthesizer. This system was implemented to provide configuration for four speech speeds: 1 / 0.85 / 0/75 / 0.5.

During the experimental stages it was a time demanding process to listen to all the notifications every time, so with this options the supervisor is able to cancel the notifications to reach to a certain activity faster. During a normal use of the application there is no need for a supervisor but during the tests when sometimes I was dealing with multiple devices and users in the same time I decided that it would be better to be able to reach to a certain activity faster and then hand the device to a visually impaired person so that the results of the research to be noted on the desired tool only. For example when the piano was implemented It would have been a waste of time to wait and listen to all other notifications and remarks so all the testing devices were configured fast with the piano tool already open.

## 4.3 Adaptation and customization to special needs

### 4.3.1 Application Theme

By default, in Android development there is a standard theme for applications. The default theme is called *AppTheme* and requires the application to meet the following criteria:

- top menu bar
- settings button with standard or similar icon
- visible notification bar with phone status, battery and clock

During experimental sessions (chapter 7) I've noticed that most of the time, volunteers interacted with the edges of the screen trying to find the vibrating line, accidentally pressing the settings button or triggering the drag method for the notification bar that was preventing them to continue without the presence of a supervisor to help them

The theme used for this application for visually impaired people needed an entirely different design, specially crafted for the blind, so it was required to alter the default theme, to remove the menu bar and force the application to remain full screen. Also the notification bar was hidden in order to prevent unwanted triggering.

### 4.3.2 Text-to-Speech Engine

Since the application uses audible feedback in a multi-language environment, replacing the standard text-to-speech voice synthesizer was needed. IVONA Text-to-Speech by Amazon [82], has a native Android application [83] and was chosen for this type of system.

This is a voice synthesizer that can convert written text into speech in a large number of languages and is available for Windows and Android. The advantage of using it instead of the default synthesizer is the large number of languages and voices that are available for free in the alpha version, and it also provides more fluid and natural speech output. The available languages are show in Fig. 4.8:

*Fig. 4.8 Available IVONA Languages [82]*

First the application is downloaded on Android devices through Google Play. Then the desired languages can be installed as add-ons. The application for sighted people currently only uses English and Romanian, so these languages have been installed and tested. In order to function properly, Ivona Text-to-Speech (TTS) must be selected as the preferred text-to-speech engine in the phone settings, as seen in Fig. 4.9.

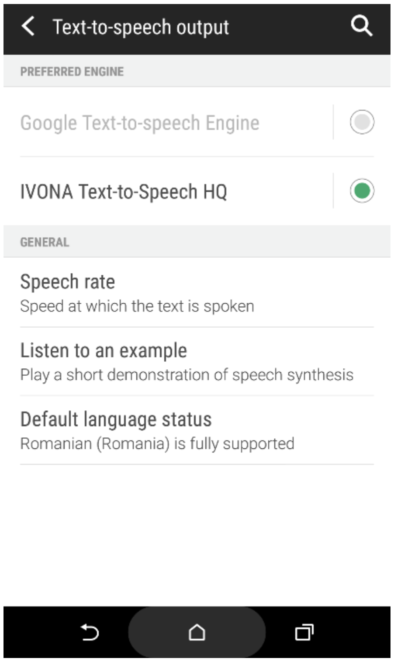


*Fig. 4.9 Selecting IVONA as preferred text-to-speech engine*

In order to use the voice synthesizer a series of steps need to be performed. The most important of these are:

- reference additional extension libraries;
- implement listener interfaces;
- declare and work with *TextToSpeech* variables;
- check availability of *TextToSpeech* functionality on the device;
- initialize methods for detecting available languages;
- create custom methods for receiving text parameters and calls specific for TTS engine methods to synthesize the corresponding speech;

### 4.3.3 Vibration

Guiding and teaching visually impaired people is a process based on the feedback from the device. Any person can use the application individually, without the need for a supervisor. Since the application can be installed on any mobile device with touch screen and Android operating system, people with sight problems can use it at home and learn very quickly. To guide the user during the learning process, the application uses both sound and tactile feedback. These methods were chosen because most of the visually impaired people have highly developed senses of touch and hearing.

There are two types of vibration used within the application:

- Continuous length vibration for a given number of milliseconds.

```
vibe.vibrate(100);
```

- Periodic vibration according to a predetermined pattern. The template uses milliseconds to express the length of pauses and the duration of vibrations. The second parameter of the vibrate function is the repetition. If we do not want the vibration to repeat, we must set the parameter to "-1". If a repetition is desired, we must set the index where we want the template to return.

```
long[] pattern = {0,200,100,200,100  };
vibe.vibrate(pattern,-1);
```

Until version 5.0 of Android, specific vibration methods and patterns were available for developers but since hardware producers implemented various hardware embedded methods to control patterns, two devices were vibrating different for the same software settings. Since version 5.0, all predefined patterns were removed from the software development kit, all system functions have the same vibration notification, and developers are allowed to control the vibration motor with custom vibration methods.

By using the two types of software implemented vibration control exemplified above, any Android device will vibrate likewise when running this application for visually impaired people.

### 4.3.4 Disable hardware buttons

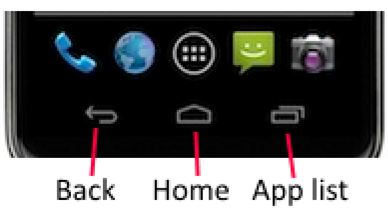


*Fig 4.10 Android quick buttons*

Standard buttons as seen in Fig. 4.10, are hardware buttons that every smart touchscreen device has for quick functions. Depending on the device type those buttons can be emphasized or illuminated.

Tests performed with visually impaired users during experimental stages (chapter 7) revealed that those button were repeatedly touched involuntarily, closing or minimizing the desired activity. In order to prevent this problem, the change consists in overriding the standard methods and disabling the functionalities.

Disabling standard button is not recommended and represents a security problem for normal applications, but special purpose applications may disable them temporary.

### 4.3.5 Android Gestures

In order for the application to react in the desired way to a single or double tap on the screen or in order to implement the swipe back gesture, the predefined Android gestures needed to be override. It takes certain steps in order to achieve these changes:

- include the necessary libraries;
- override all preimplemented gestures (onTouchEvent gestures, onDown, onFling, onLongPress, onScroll, onShowPress, onSingleTapUp, onDoubleTapUp, onDoubleTap, onDoubleTapEvent and onSingleTapConfirmed)
- instantiate the gesture detector in the context of the application
- implement new gestures

## 4.4 Remarks and conclusions

Essential features and hands-on experience throughout the entire application development were acquired with the help of visually impaired volunteers included in the experiment. Important aspects, tests and results can be found in chapter 7.

### 4.4.1 Feedback guided scenario

The key to helping visually impaired users to correctly use the application is to provide feedback for every move and have a friendly interface. By friendly I mean perfectly adapted to people who suffer from eye disorders. Such users are special, they act like children when dealing with a touchscreen applications. Every move they make starts with a shy exploration of the screen and from time to time they get scared because of a vibration, sound, edge of the device and they raise their hands and start over with the same fear of unknown.

The tools were developed so that the device must be held in "landscape" mode. If the device is in "portrait", the application requires the user to rotate the device in order to continue. I never thought this would be such an important thing until during the experiments and testing I saw how visually impaired people react when they are interacting with a touchscreen device, turning on all his sides and feeling his edges. I have decided to add this feature just after observing that during one of the initial meetings all of the subjects were confused about the correct orientation of the device.

Another important aspect in the process of designing the applications was the use of colors: contrast between black and white, colorful piano, and red edges. In the first stages, the entire application was built using simple standard android controls, because blind people don’t really care about shiny UI’s. During the meetings, I have realized that sometimes some of the users impaired started to get very close to a device with their eyes because they could see certain shades of light. Following this idea the menus and activities got a new look with black and white contrast, red edges, full red notification screen, etc. This extremely important discovery has no influence for totally blind people but can bring a huge boost for people who can distinguish between bright and dark regions or small colorful areas. Thus, such people can more easily use the application.

Without the feedback and the live observations on how visually impaired people interact with modern mobile devices, a conceptual standard model would have failed to produce significant results, but a feedback guided research and development was the key to discover what is actually the correct process.

### 4.4.2 Learning through play

Learning through play is a concept [77] encountered in education and psychology that describes playing as a method for developing social and cognitive skills, emotions and self- confidence required for every learning task or activity. An important aspect on how this process is applied concerns the technique that has to be adapted to the importance and perspective of each individual learning environment.

Nowadays, the mobile technologies, devices and gadgets are top wanted products for all age categories, but especially for children. This is a contemporary trend and many are starting to use these instruments for communication, recreation, online experience, playing, as well as learning or work related activities, etc.

If we would like to know which modern device is the most adored by children and teens we would have a problem choosing between the tablet and the smartphone. Studies [78], [79] have shown that nowadays more and more children of all ages are giving up on their basic mobile phones and ask for smartphones. Regarding tablets, the number of children who are using this devices is going up every year by at least 20%. This evolution also reflects the changes in how younger people browse the internet or use online services and apps.

Now that we are aware of the implications brought by the contemporary trend in learning through play, with positive and negative effects, we can turn everything in our advantage, striving for a better education system, which uses modern, enthusiastic approaches and well adapted pedagogy.

One of the most important conclusions of this thesis is that we can get this modern approach, increase the accessibility of games and tools, and adapt it to the education process of visually impaired people. The geometrical shapes and piano activities are following the exact same principle. Although this research is in the early stages, with training, patience and devotion visually impaired people can use learning through play to achieve outstanding results.

### 4.4.3 The importance of learning basic shapes on touchscreen devices

In order to benefit from the technologic development, the devices need to be adapted to the visually impaired people's necessities. The results depend also on the effort these persons make in order to learn how the devices work. A good starting point is learning the basic geometric shapes. The same way children learn how to draw lines, so that they can write letters and numbers afterwards, blind people have to learn how to draw lines and basic shapes in order to further develop other important abilities. Learning these shapes on a touchscreen will help the user track more complex objects. An important advantage of this learning method is that users are able even to understand a map through tactile and audio guidance. This way, people with sight problems will analyze the basic geometric shapes on the screen and will rapidly identify the route they have to follow. This solution could be a great add-on or improvement for a map application [74] for blind people. Fig. 4.11 exemplifies this situation.

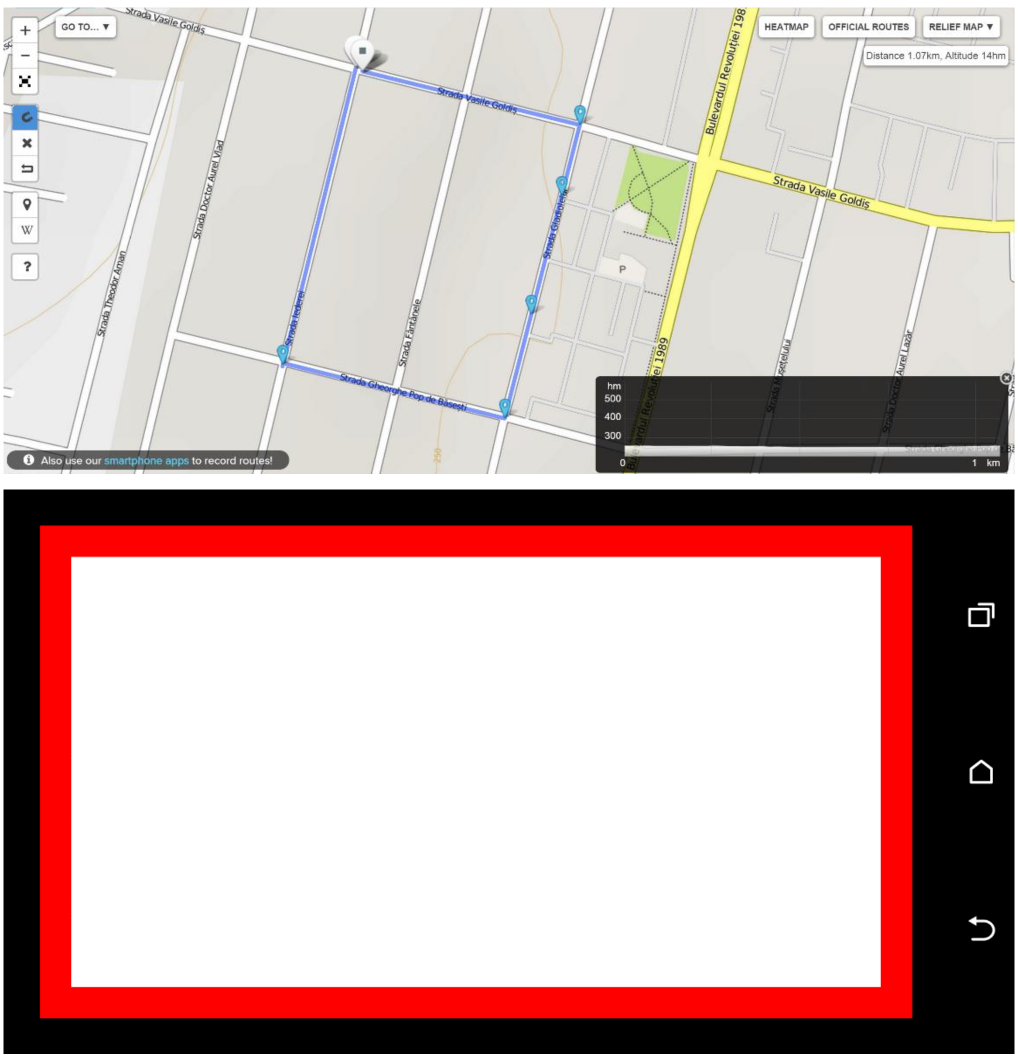


*Fig. 4.12 Following a rectangle path on a digital map*

### 4.4.4 Why is Piano training essential

Piano training using the implemented piano activity has two different purposes, an obvious one and a hidden one:

Purpose 1: Piano Simulator

- Represents a full octave of a real piano
- Can be used as a great music tool
- Interactive and entertaining music educational for children
- Challenging instrument for adults and professionals

Purpose 2: Concentration and skill training for touchscreen interaction

- Trains the capability of concentration regarding the feedback received
- Forces the user to use two remaining senses: touch and hearing
- High contrast sound buttons for low vision or colorblind people

After few testing sessions all the subjects from the experiment started to love the piano, they even asked for headphones to play as long as they want without disturbing others.

The piano training might look simple for people with healthy vision, but mastering this tool can bring many advantages for people with eyesight problems:

1) Getting familiar with a multitude of buttons can increase the ability of using more complex menus
2) Being able to feel 8 – 16 different vibration/sound feedback just by triggering touch, can be a road opener for using multiple wearable devices
3) Similarity in design with smart house remote control touchscreen applications can be a great plus when it comes to controlling the environment so it could became an accessibility tool

### 4.4.5 The importance of hearing and tactile feedback when using a mobile device

The technological progress is a big advantage for all people. The fact that medicine evolves, putting at everyone's disposal complex assistive devices, represents a big step forward for visually impaired people. In some cases, however, these people can face difficult problems while trying to adapt to touchscreen mobile devices. The challenge is to get used to phones and tablets that do not have any buttons. The buttons help them coordinate and do simple tasks, such as calling or sending a message. Although modern devices are developed in order to perform complicated actions in a smart, simplistic way, they are not yet fully adapted to blind people necessities; therefore they cannot easily use all the important features [81].

The most significant aspect that blind people rely on when using a device is the feedback or notification sent by the device. Thanks to the hearing and tactile abilities that visually impaired people can achieve, when the accessibility option is activated [75], the device becomes more user-friendly. Depending on the action performed by the user, sounds and vibrations will be enabled when the user presses a specific element. For fulfilling his purpose, the element needs to be long pressed or double tapped, depending on how the system is implemented. The vibration is controlled by the vibration motor inside the device, which can be controlled by the programmers during the app development stage. The motor can vibrate different periods of time having different intensities or it can follow a specified vibration pattern.

### 4.4.6 Working in comparing groups VS following individual performance?

Splitting the subjects who participated in the research experiment into two groups would be a classic research solution [76] to observe if the experiment has a point and if the results can be quantified. After 6 months dealing with visually impaired people, my opinion is that this idea does not apply here because of the following reasons:

- Each individual has unique skills, which are very different comparing to others.
- Subjects are very different because some are relying more on vibration, touch, sounds.
- Because of the obvious differences in the learning process it is very hard to say that user1 would learn faster to follow a rectangle map comparing to user2 just because one of them has the touch/vibration ability and the other perceives sound better.
- Visually impaired people have an extremely high confidence for the other fellow companions who suffer from similar eye disorders and are easily influenced from their decisions and opinions.

Measuring individual performance on an extended period of time might be time consuming for both the research team and the subjects but it offers the most precise and pertinent study and has the following advantages:

- Dealing with reluctance to technology is the first step and can be controlled easier when you deal only with one subject because you can understand he's special needs.
- Everything has to be extremely customized: the speed of the menu voice, the sound volume, difficulty of the exercise, colors of the menu (influencing multiple cases of eye sight problems), vibration intensity (depending on the device physical vibration motor), etc.
- It is time consuming to find the optimal customization for an individual and then work with that scenario and if you would have to extend that customization to a group it could be very close to impossible.

### 4.4.7 Encountered difficulties

During project development, implementation, and experiment, several difficulties had been encountered that were, ultimately, successfully solved. Some of these are:

- Understanding blind people, talking with them and guiding the entire work based on their opinions, beliefs and feedback.
- Obtaining a high degree of accuracy in guiding the user by means of the vocal synthesizer and vibration. These indications came to be very accurate, the device thus guiding the user through every single step, explaining the actions needed to be taken and how the interest activity is designed.
- Design for the first octave of the piano. This situation required detailed study of XML coding, design layers and precision for auto-scalable UI.
- On touch surfaces you can get only the coordinates of the point of contact, with the exact outline of 1 pixel, thus making following and guiding the line of a circle almost impossible;
- This was solved by drawing two overlapping circles of different radius. The size difference represents the degree of difficulty requested by the user, the outline thus having the possibility to become wider or narrower.
- Unintentional pressing of the physical "back" button when using the application. In the first stages of the test experiment approximately 50 % of the time was spent just dealing with this aspect. This problem was solved by disabling the button on the device and implement a dedicated gesture that directs the user to the previous desired activity.
- Visually impaired people, because of their condition, are very insecure and afraid of new things that is why during initial meetings most of the subjects showed an unexpected reluctance to the touchscreen technology. After the younger subjects (under 30) started to enjoy the application they became some kind of tutors for the others and from that point the overall experience got better. This shows that this category of people would better understand and trust other people with the same condition. From this point every new idea was tested first on a younger subject and then we asked him to share his experience to others.
- Understanding the text sent through the synthesizer was a serious concern because everyone has a different understanding capabilities of the robotic voice and a unique voice for everyone was a struggle. The possibility of changing playback speed rendered by the voice synthesizer was implemented and added as a customization, so that the understanding of the voice became smoother and adaptable to each subject.
- Every time a new important feature was added (Romanian and German language, colorful menus, customization of the voice, etc.), almost all the subjects were anxious to try it and their behavior started with a high degree of insecurity and their performance began to be clumsy. After a while, I have decided to explain the new feature not in the same meeting but in the previous meeting. This way the happy impatience was consumed (questions, answers, group discussions) and when they had to deal with the new feature the overall experience was way better.

### 4.4.8 Future work

This research idea will be further studied in order to improve the learning process of visually impaired people when dealing with applications on touchscreen devices.

Some of the future research and implementation ideas are:

- Increase the support for internationalization with other available languages
- Introduce the concept of understanding 3D geometric shapes (cube, pyramid, etc.)
- Add more complex objects which will be easier to understand as they are based on the previously learned geometric shapes (ex: House - pyramid over cube, Car: circles and rectangle, etc.)
- Introduce new educational activities involving the process of learning letters and numbers.
- Build a version of the application for the iOS platform because a high percentage of those with sight impairments use Apple devices. These devices have increased accessibility capabilities but issues might appear because the platform is not so permissive when it comes to custom programming standard features.
- Integrate a math learning tool for counting geometric shapes on the screen.
- Extend the experiment on a larger scale with a greater number of subjects.
- Apply the same experiment to normal people blindfolded to observe if the results are similar.
- Design an architecture with user accounts and connectivity to be able to store the data and remotely monitor user experience, feedback, etc. This way people who participate at the experiment could use the tools on their devices at home.
- Observe the evolution of every user over an extended period of time.

# 5 Perceiving colors haptically

## 5.1 Haptic Tool for learning geometrical concepts

In Sweden, pupils who are visually impaired don't go to special schools, but they study in normal classes. This situation makes them the only pupil with such problems in their own class. Therefore, the study [58] presents two visual and haptic applications that focus on learning geometrical concepts regarding group work in primary schools. The first application (Fig.5.1) represents a 3D static environment and its purpose is to use tactile feedback in order to learn to differentiate between different angles.

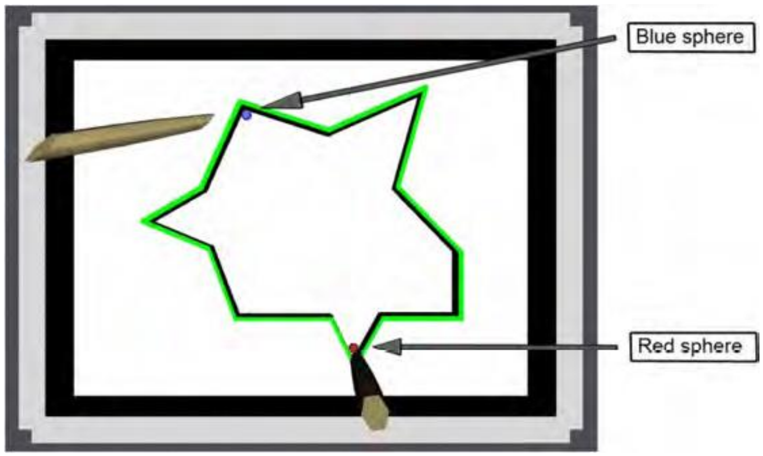


*Fig. 5.1 Static Application [58]*

The second application represents a 3D dynamic environment which is used to learn spatial geometry (Fig.5.2).

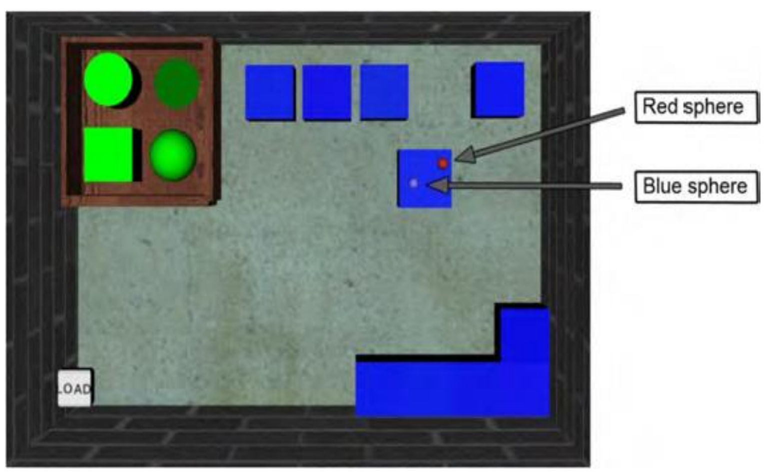


*Fig. 5.2 Dynamic Application [58]*

**Results**

After a series of experiments that were conducted, the conclusion was that it's much easier for a visually impaired pupil to make important decisions and to take the initiative in a static environment, rather than in a dynamic environment. Moreover, it has been discovered that, when using the static application, a pupil with low vision is aware of what is happening on the screen and what the other pupils are doing. Also, a visually impaired pupil was capable to move the geometric shape and reported to the others what angles had been categorized. He obtained a mental image of a star-shaped figure while quickly navigating through angles.

Regarding the static application, the reactions were all positive. Every pupil considered that working this way was an easier task. Both visually impaired as well as sighted pupils concluded that is not difficult to navigate and that were no problems in finding the lines.

Concerning the dynamic application, the reactions were mixed. Every pupil, including the visually impaired, described the fact that it is not complicated to hold or to pass objects to others. Even though the pupils considered that they would prefer to work in the dynamic environment, they concluded that it's a little bit more difficult to use. This opinion comes from the fact that they were engaged in manipulating and building objects in ways new to everyone.

**Conclusion**

The results of this study demonstrated that sighted and visually impaired pupils that work in groups in a visual and haptic environment, can obtain and keep a common base of the scheme and the objects in a workspace, as long as there are no major changes made to the environment. Most importantly, the possibility of achieving a common perspective allows low vision pupils to be included in the group work process.

## 5.2 Haptic Device to relay 2-D Texture-Enriched Graphical Information

Studies show that people do not perform well when it comes to interpreting information from raised-line drawings, on account of two reasons. The first reason refers to analyzing lines that describe parts of an object and the second one has to do with the portrayal of the direction of a part. The main idea of the study described in [59] is to develop a device that uses the sense of touch in order to transmit 2-D texture enriched graphical information.

**Results**

The main function of the device is to interpret color from a visually formatted diagram as different vibration signals in the interest of simulating textures on a tactile graphic (Fig. 5.3). The device works in the following way: using a color sensor, the light emitted by the surface of a computer or an illuminated screen is detected, and it is transformed afterwards in a vibration on the tip of the finger using a piezoelectric speaker.

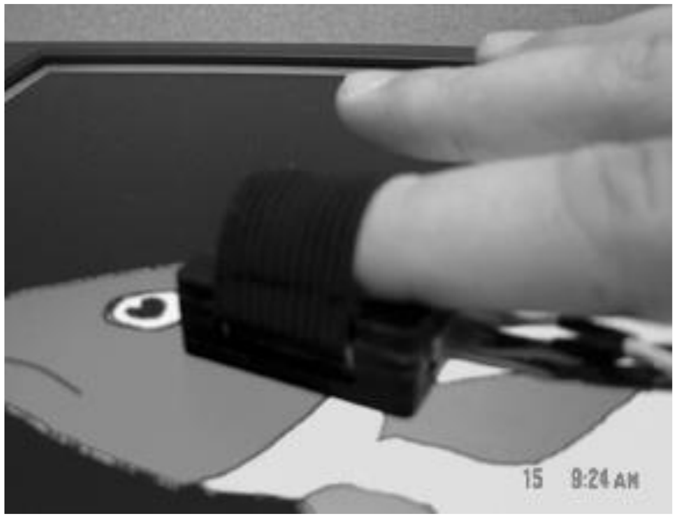


*Fig. 5.3 Device interacting with a computer screen [59]*

Additionally, the system can be easily developed so that it includes more individual devices, given the fact that the proposed method allows the parallel functioning of several devices on the tip of the fingers. The weight of one device is less than 100g, which means that using 5 devices simultaneously will produce a total mass of the system of less de 500g. To reduce costs, commercial components have been used, so that the total expense for one device is $25.

## 5.3 Learning and perceiving colors haptically

For humans, color perception is an essential part of spatial processing and it plays an important role in social interactions. Therefore, there is a need to develop systems than can extract information about colors to make them accessible to visually impaired people. The system proposed in [60] is based on a methodology that represents colors as textures using a tool which exploits the sense of touch. The aim of this approach is to allow color perception and to ensure a base to evaluate color similarity.

**Results**

This study proposes two experiments. The first experiment tests the ability of the user to perceive colors using the suggested system. The second one tests the ability of the user to perceive similarity between colors. For testing, four groups of users were recruited. The first group includes 5 blind individuals (B group). The second group includes 5 sighted individuals, but who were tested blindfolded (SB group). The third group includes 5 sighted individuals, who were tested in normal conditions (S group). The last group includes individuals from S group, but who were tested blindfolded (S/SB group).

Fig. 5.4 shows the fact that all groups can achieve a recognition accuracy of 100% after a number of learning phases. This suggests that the proposed approach, in naming a limited set of colors, is a valid one.

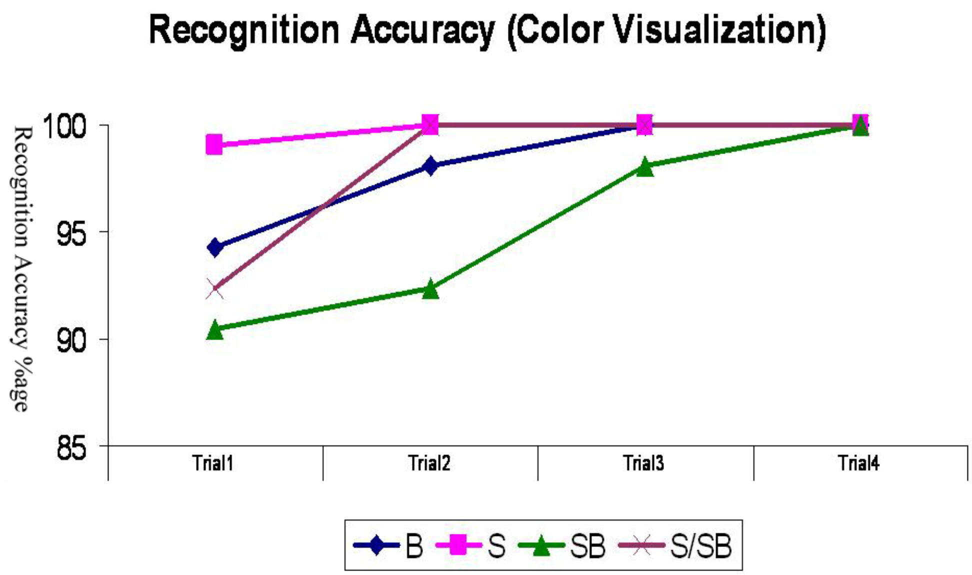


*Fig. 5.4 Recognition accuracy [60]*

For the second experiment, 2 groups of users were tested. The first group includes 5 visually impaired individuals and 15 sighted individuals (S, SB, and S/SB) who went through the first experiment, group that was named *trained group.* The second group has the same structure as the first one, but the difference is the fact that this group didn't go through the first experiment and it is called *control group.*

*Fig. 5.5 Color Wheel [60]*

Fig. 5.5 shows a hexagonal representation of the color wheel. Fig. 5.6 up shows the scaled 2 dimensional space acquired for the trained group and Fig. 5.6 down shows the 2 dimensional space acquired for the control group. The results show that the perceived similarity between pairs of colors produces scaled spaces which are highly compatible with the visual similarity spaces modeled as the color wheel.

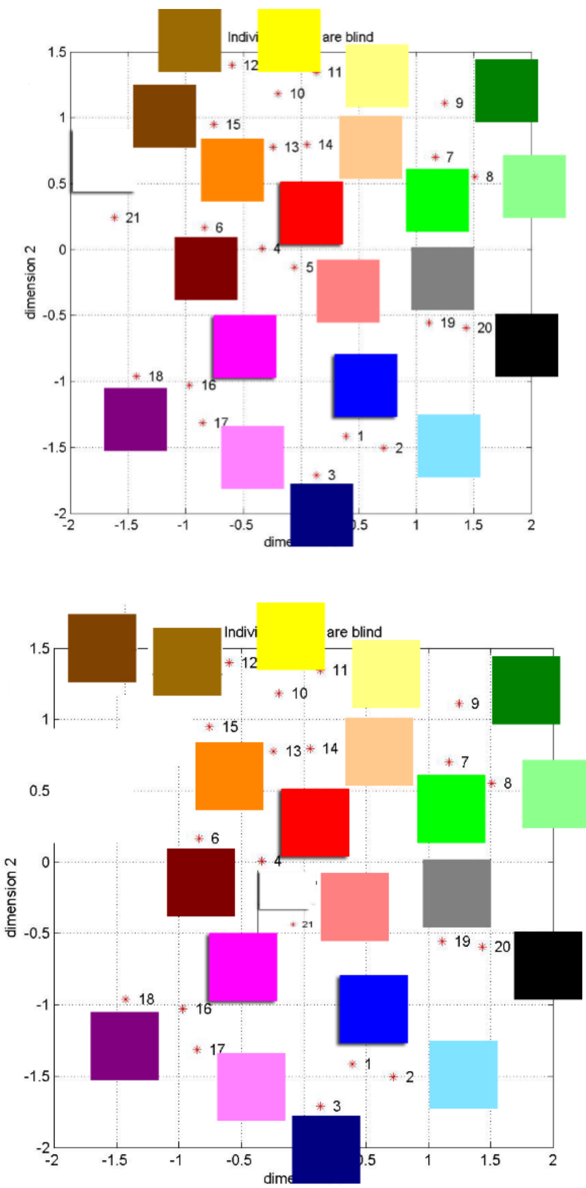


*Fig. 5.6 – Trained Group (up) vs Control Group (down) [60]*

Regarding the real-time perception of color, the article explains the use of a CyberTouch glove that operates with vibration motors on each of the five fingers and the palm.

## 5.4 Haptic Exploration of Virtual Paintings

The loss of the sense of vision limits the access of blind or visually impaired people to environments like aquariums or museums, which can provide learning opportunities, as well as personal recreation. Even though museums that offer a description of paintings using an audio recording already exist, this does not supply a personal experience of the style and the eloquence of the artist. The focus of the study described in [61] is to illustrate digitally formatted paintings, using a representation based on the sense of touch.

**Results**

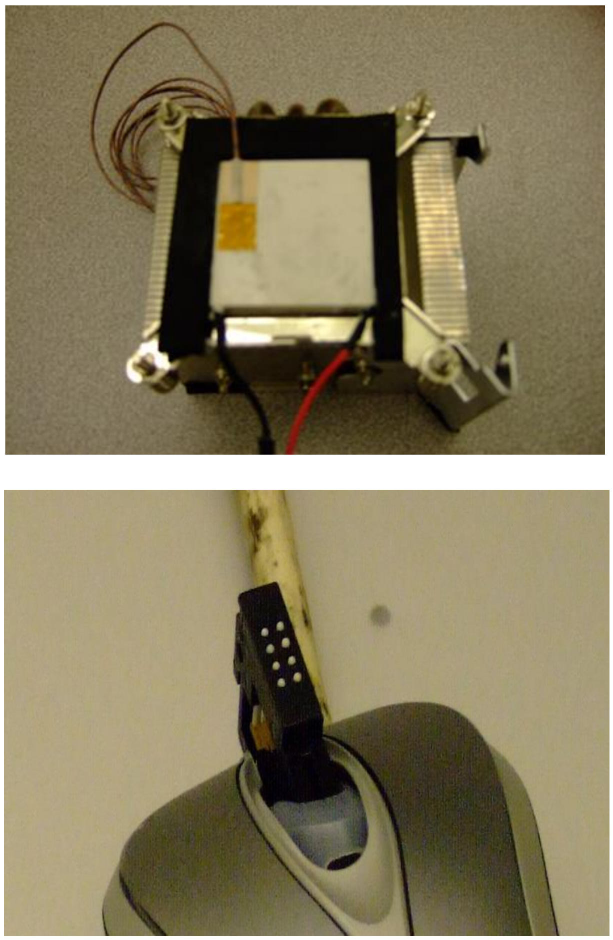

*Fig. 5.7 Thermal display (up) and Tactile display (down) [61]*

The device (Fig. 5.7) that was used consists of a pin matrix display to the fingers in order to transmit tactile texture information about brushstrokes, using a thermal display on which the caloric spectrum of colors is mapped. Also, for the adjustment of tactile and thermal feedback, a location sensor within the painting is used. This is necessary so that the painting is presented with a contrast.

The article presents an interview with two visually impaired people and a blind individual. After the specification and the clarification of the aspects concerning the concept, all of the three individuals concluded that they would work with the device if it can be used in schools or museums for free. Likewise, they would be willing to adapt to this technology.

Concerning the future aspects of the concept, the authors wish to test different methods of representing the brushstrokes and the colors, in the interest of determining which one is more efficient. Furthermore, they desire to use different methods to display the style and the feeling of the virtual painting. Last but not the least, the authors hope to develop a display system, conversion methods and display methods, so that public and private art galleries paintings can be illustrated.

## 5.5 Multimodal Drawing System for Visually Impaired

A lot of individuals who are blind or visually impaired are interested in drawing tactile pictures, some of them being able to accomplish this using raised-line drawing kits. However, giving the fact that the raised-line drawings obtained with these kits are erasable, the static drawings become a problematic deal. Images are conventionally perceived as visual entities, yet the important part of an image is not the concerned perceptual modality, but the spatial arrangement of information. For visually impaired people, this information must be represented in a non-visual accessible way. In order to find ideas regarding the new computer-based drawing system, a group of people was tested [62]. Using on the results, a new design concept has been generated for a multimodal device which can improve, based on previous solutions. This device can offer a new way for visually impaired people concerning graphic editing and viewing.

### Results

Based on the feedback received from the tested group, a new computer-based drawing system was developed. This consists in a multimodal representation that has the capacity to engage the auditory, haptic and visual sensory systems. The system will compensate the disadvantages brought by previous designs: the picture can be deleted or edited, the digital copies will be instantly accessible, it will be assured a haptic representation at a convenient price and the available active surface will encompass the entire graphics tablet. The system will be capable to work using only the haptic system, being accessible to visually or auditory impaired individuals and for people who prefer this method. The added auditory portions will amplify user's experience.

When it comes to the focus group results, a grid system will be implemented, which makes it possible to divide the drawing surface in m*n sections. Keyboard commands will evoke a verbalization of grid location, will allow the user to record a verbal description of what it is contained in the grid. Most remarkably, the system allows the user to draw in textures, corresponding to colors, which can be tactually distinguished. The representation of several different textures is possible. These textures are used in order to draw lines or to fill shapes or areas of the drawing, based on what the user desires.

Until now, a limited version of the new design has been implemented in MATLAB using the haptic device. A more updated application is being implemented in C#, with the plan of incorporating Microsoft SDK’s. This can allow the use of multiple pointing devices. The completed version will be user-tested in the near future.

## 5.6 Assistive Haptic Feedback for Visually Impaired Internet Users

Haptic technology can assist visually impaired people to overcome problems that occur when browsing the Web [63]. The assistive technologies are used by blind individuals to access the Internet. Screen readers, JAWS, Windows-Eyes or Braille output devices insure tactile or audio representations of the information within a page. However, these instruments have several restrictions when it comes to the navigating process, by presenting information in a linier way, which is time consuming. The study [63] proposes a structured participatory-based approach, in order to develop haptic sensations for the exploration of web pages. Furthermore, the study focuses on exposing the preliminary results by showing how HTML elements can be represented using tactile feedback.

**Used methodology and results**

The authors propose a 5 steps method (Fig. 5.8). Its purpose is to help developing the haptic feedback:

Step 1 and 2: The task analyzing phase has shown that a screen reader has been very useful in accomplishing a search task, but it didn’t provide all the help required by users. These steps have helped in identifying areas where the additional feedback can be conducted.

Step 3: The sense of touch has been considered, by the tested group, to be an efficient environment and it can emphasize elements within a certain Web page.

Step 4: The participants have been capable to suggest methods of improving the design, by expressing different creative new ideas, if they considered that the previous suggestions have not been adequate.

Step 5: The focus group has been capable to evaluate prototypes, developed as a result of the other groups.

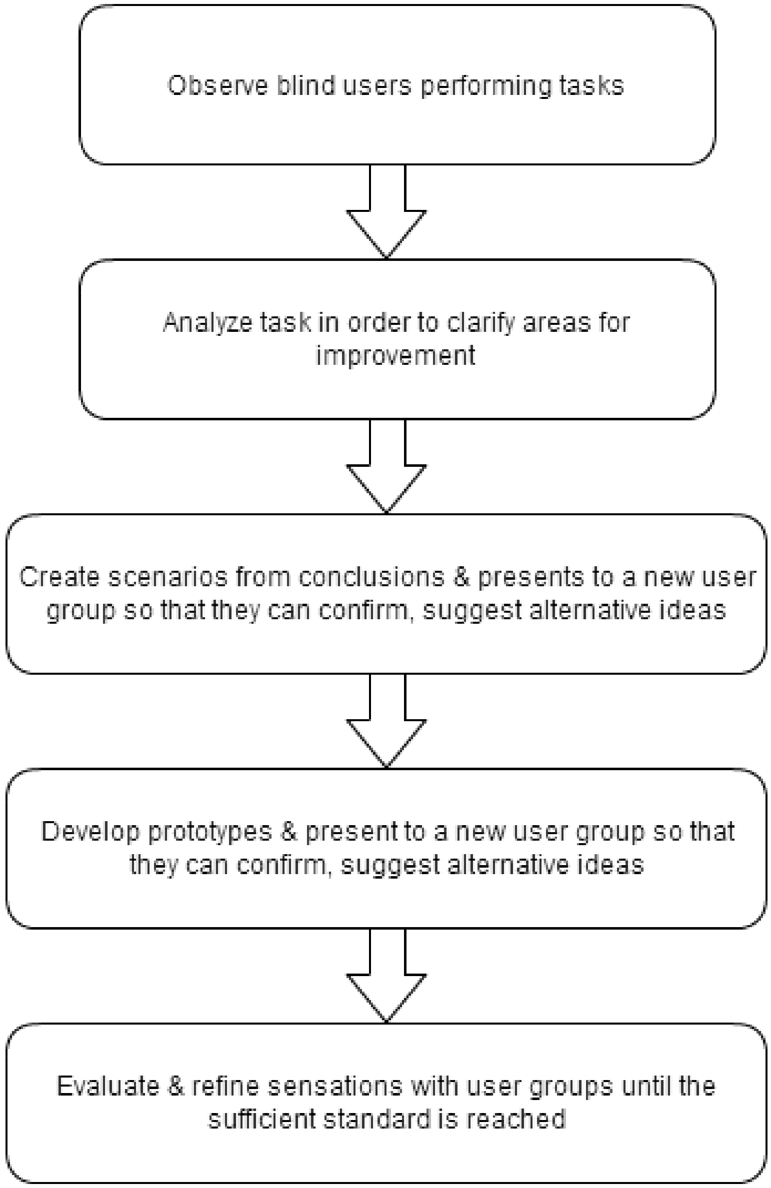


*Figure 5.8 Step method to design haptic feedback [63]*

The findings have been compared to mappings of other haptic interfaces, suggesting the need of an adjusted design. A new step is to improve and to rigorously test the mappings. Another purpose is to broaden the vocabulary of elements and to develop a set of guidelines so that these sensations can be applied in a web interface.

## 5.7 Conclusions

Color is an essential component of spatial recognition and there is a requirement to invest in systems that can help individuals who are blind or visually impaired to learn new methods to perceive colors [57]. Individuals who are color blind and endure different types of color blindness such as achromacy, tritanopia etc. encounter various problems in their daily lives. Blind individuals suffer from color deficiency as well. Individuals who are congenitally blind have to learn about color through artificial ways. A person that experiences blindness at later phases, has the sense of color but the absence of sensory data belonging to color, influences everyday activities. Individuals that suffer from such sensory and cognitive afflictions can be assisted by systems that permit color perception. Regarding the sense of touch, the development of haptic technologies have been growing lately and economical devices are becoming more broadly accessible.

Interesting results are obtained with haptic feedback using different sensors and modern devices. Using this assistive tools allows decisive perception of the environment and helps in object detection, analysis, scene understanding and other spatial tasks.

The study conducted in this chapter proved that visually impaired people can adapt and learn to use various haptic devices to understand and perceive colors. Bold results obtained in these experiments are encouraging new ideas to emerge.

# 6 A gamepad training application for color perception

## 6.1 Description

People with visual disabilities that are completely or partially sighted cannot perceive surroundings like normal people. Without the knowledge of how colors or specific forms look like, they encounter difficulties in everyday life. It is known that the human brain adapts and compensates by increasing capacity to auditory and tactile sense when visual sense is low or totally missing. This is why blind people develop special skills in areas such as music or physical therapy.

Without vision, the sense of touch becomes an additional key source of information. There are two hypotheses [85] about how the sense of touch improves blind people. The first supposition highlights that the tactile acuity improvement occurs because people blind are counting more on the sense of touch. A second hypothesis, however, say that the very lack of vision acuity increases tactile sense. Studies have shown that people who are proficient reading Braille, those who spend hours a day reading with fingers have a much higher finger sensitivity compared to healthy people who read normally using vision.

For humans, color perception is an essential part of spatial processing. It allows decisive perception of the environment and helps in object detection, analysis, scene segmentation and other spatial tasks. Likewise, color perception plays an important role in social interactions. Color is not perceivable directly through the touch sensors in humans, because, as a feature, is entirely visual. This is one reason why presentation of color data to individuals who are visually impaired constitutes a complicated issue.

Relying on this information and after carefully studying the state of the art solutions and concepts (chapter 5) I am proposing a method that aims to explain the colors using vibration. This technique presents a new way to make an image vibrate using a standard Xbox gamepad controller. This solution allows sighted people to understand at some level what a picture, a painting, or a friend looks like.

Code snippets and technical implementation details can be found in [A2].

## 6.2 The haptic system

The haptic system consists of:

- a Windows Forms application with a suggestive interface for the supervisor
- the Xbox One gamepad controller

With the purpose of achieving special tasks, the Xbox controller and the application must have a constant communication with the user.

*Fig 6.1. XBOX One Gamepad*

The XBOX One gamepad controller (Fig. 6.1) has two vibration motors (Fig. 6.2), a low frequency and a high frequency motor, one in the base of each grip. The functionality of these motors, is to supply force feedback effects to the user. A vibrating motor is essentially a motor that is improperly balanced. In other words, there is an off-centered weight attached to the motor's rotational shaft that causes the motor to oscillate. The amount of oscillation can be changed by the speed at which the motor spins.

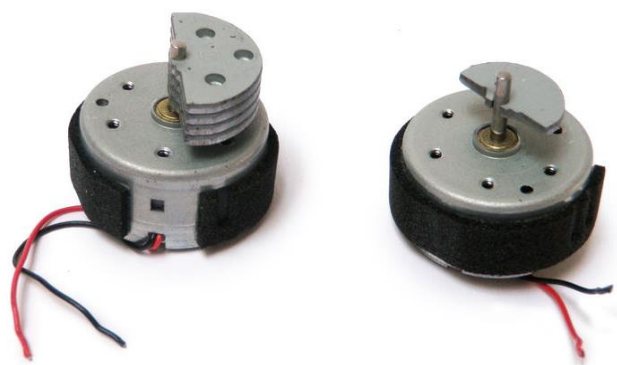

*Fig. 6.2 Vibration Motors*

Fig. 6.3 displays the learning stage associated with the haptic system. The supervisor configures the application, selects the different levels of vibration, each one having associated a certain color. The blind individual that wants to learn the colors uses the Xbox gamepad, so that he/she can receive tactile feedback.

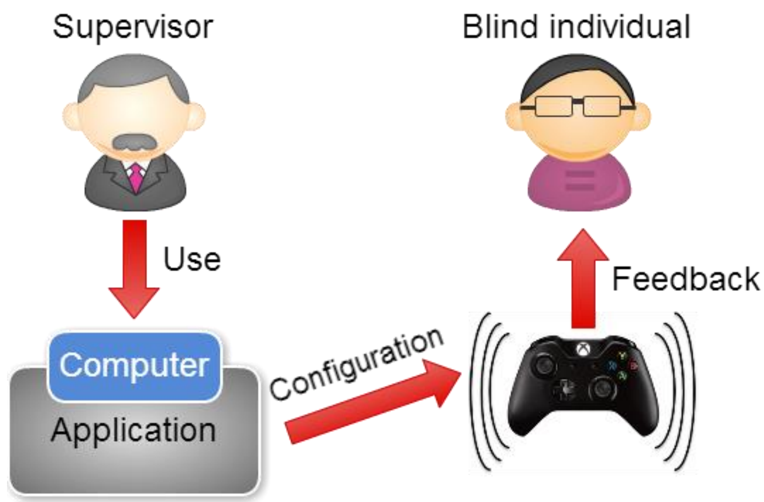


*Fig. 6.3 Learning Phase*

Fig. 6.4 shows the use of the haptic system in the perception phase. After the image is loaded on the screen, it is processed and displayed right next to the original version. The supervisor has the ability to visualize the image, in two different formats:

- original
- processed

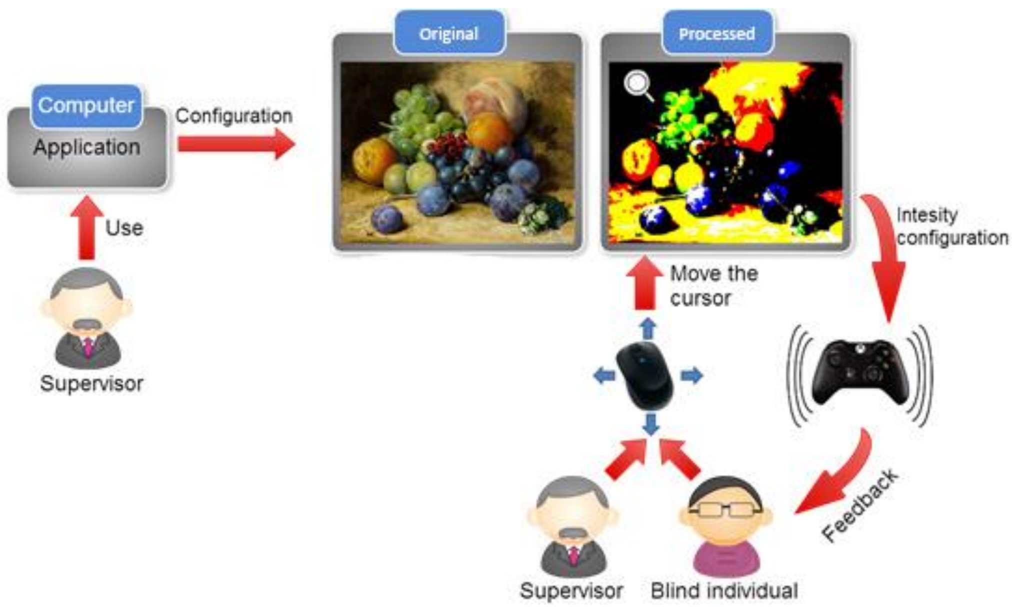


*Fig. 6.4 Perception phase*

The supervisor has the capacity of selecting the input source: a static image or real live webcam capture. The source can be loaded on the interface, processed and then displayed alongside with the original one. The supervisor can configure different color parameters, so that the source can be processed and displayed according to his personal opinions regarding the correlation of the source to the real life, the user having the possibility of choosing the best configuration.

When the mouse cursor is moved on top screen containing the processed image area, the gamepad controller will vibrate with the intensity associated with the color on which the cursor is located. Thereby, the visually impaired or blind individual can perceive at a certain level the colors from the original image. The mouse can be used either by the supervisor or by the blind person.

## 6.3 Choosing the perfect color set

During the initial development stages of the application, several feedback sessions were organized together with visually impaired volunteers. Their feedback and ideas were used in the feedback guided development in order to improve the application's functionalities and user interaction.

Initially, before the application development process, the system was designed to allow learning and perceiving of eight different colors representing a classic 3-bit RGB color palette.

Throughout one of the experiments that lasted about 3 hours, each individual's ability to differentiate between eight and six levels of vibration was tested. The results of this minor experiment are presented in Fig. 6.5

| *User* | *Vibration level* | *Accuracy* |
|---|---|---|
| *Participant 1 (Age: 21)* | *6* | *80%* |
| | *8* | *50%* |
| *Participant 2 (Age: 35)* | *6* | *100%* |
| | *8* | *80%* |
| *Participant 3 (Age: 61)* | *6* | *100%* |
| | *8* | *80%* |

*Fig. 6.5 First color perception experiment*

These results (Fig. 6.5) clearly suggest that after 3 hours of testing and learning, using our method, it is very difficult to differentiate precisely between eight levels of vibration. Because only 2-bit RGB would be way to reduced, from the major 3-bit RGB color palette I decided to exclude 2 colors: cyan and purple. This decision was made after studying the vital role of colors [88], the importance of colors in modern life products [87]. The final decision was that the system that allows visually impaired individuals to perceive and learn colors would contain 6 colors. This is a reasonable solution, as close as possible to reality using this gamepad approach.

## 6.4 Color mapping on vibrations

This haptic system, developed for blind or visually impaired individuals, offers them the possibility of learning and perceiving six basic colors:

- white
- red
- yellow
- green
- blue
- black

The entire process is hopeful due to the Xbox One gamepad vibrations. This kind of system must have the capability of allowing a type of feedback that will not distract the user and should not interfere with his/her own perception abilities.

In order to have a system that allows a fast conversion between colors and vibrations, the most important phase in the development represents the associations between colors and the vibration intensities. Consequently, the associations were made in the following way:

- Intensity 1 : White color
- Intensity 2 : Red color
- Intensity 3 : Yellow color
- Intensity 4 : Green color
- Intensity 5 : Blue color
- Intensity 6 : Black color

It is important to mention the fact that intensity 1 represents the weakest intensity of the vibration, while intensity 6 is considered the most powerful one.

First, the structure must allow of learning the associations between colors and vibrations, which should be able to help users in the second phase. The user has the ability to explore images that are loaded from the computer or real-time video display from the webcam. The video or the image must be processed so that they will contain only the six basic colors from the set. Given these reasons, the application must have a two tab interface, each one having different functionalities:

- Learning Colors
- Perceiving Colors

In the interest of accomplishing all the configurations and input selection, a supervisor must be used. He has to execute the following features

- Configure the vibration intensities
- Visualize the associations between colors and vibration intensities
- Configure the vibration time of the Xbox controller
- Select the color that needs to be learned

The Xbox controller used in the development of the application is the 2014 version released by Microsoft, which costs about $50. An important detail regarding the gamepad is that the system allows the use of an older version of an Xbox controller, which only costs12$ for the non-wireless version.

## 6.5 User interface

The user interface represents an important part in the development of the application, providing a favorable environment for the supervisor.

### 6.5.1 Learning Colors

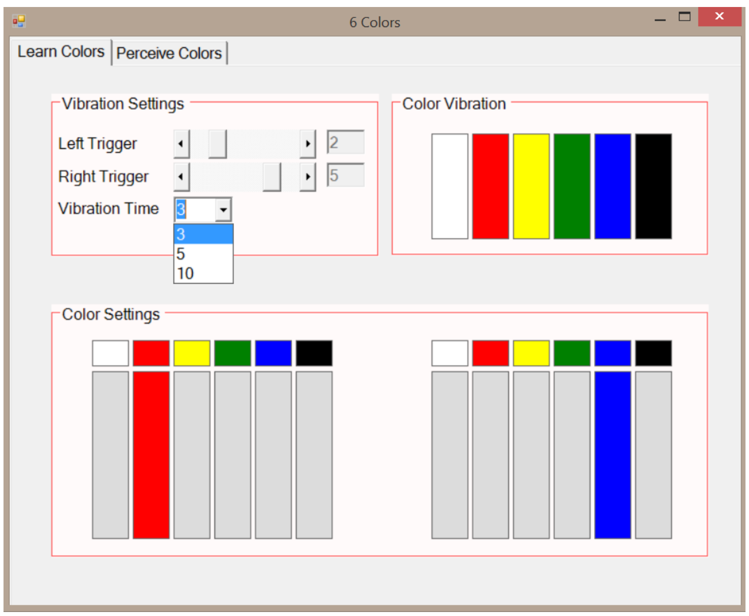


*Fig. 6.6: Learning Colors*

In this tab (Fig. 6.6), the supervisor has the possibility of configuring the vibration intensities for the controller's Left Trigger and Right Trigger. This is done by using a *ScrollBar* that can take values between 1 and 6, these values being displayed in a *textBox*. When one of the Triggers is pressed by the visually impaired user, the controller will vibrate with the intensity displayed in the textBox.

Two 6 panels sets associated with each trigger are used so that the supervisor has a way to visualize the associations between the colors and the vibration intensities. Therefore, when the ScrollBar is updated, precisely, when the intensity for one trigger is changed, a single Panel within a set is painted with the color associated with the vibration intensity.

Likewise, when one of the six suggestively painted panels from the Color Vibration *groupBox* is pressed, the gamepad controller will vibrate with the intensity associated with the color of the panel. The duration of this vibration can be set from a *comboBox*, located underneath the *ScrollBars* used for the alteration of the intensities.

### 6.5.2 Perceiving Colors

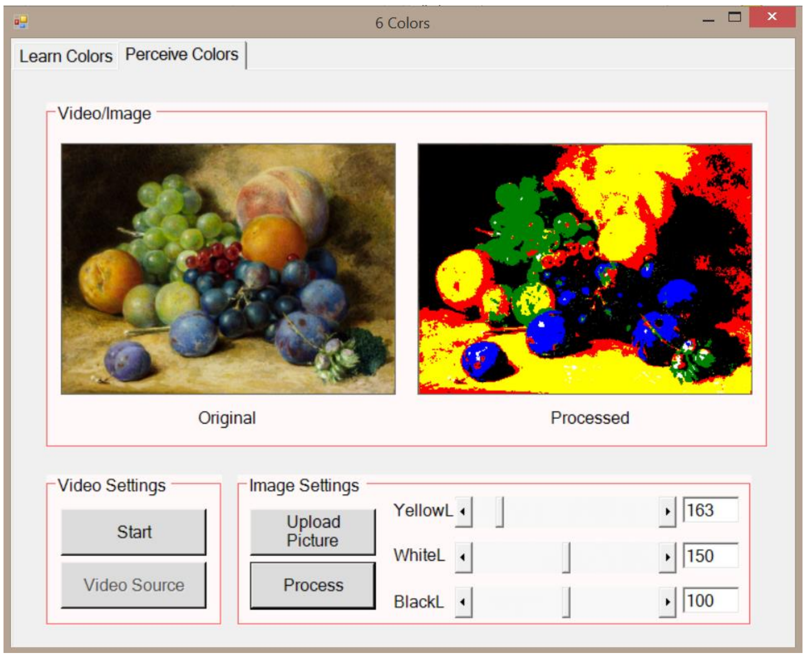


*Fig. 6.7: Perceive colors*

In this tab (Fig. 6.7), the supervisor has the possibility of loading an image from the computer by pressing the Upload Picture button or to start the video from the webcam. The source will be then displayed in a *pictureBox*, on the left side (original). When the Process button is pressed, the source will be processed and then displayed on the right side, in another *pictureBox*. The processed image will only contain the six basic colors from the initial set.

*YellowL*, *WhiteL* and *BlackL* represent the thresholds used in the pixel processing algorithm. These thresholds can be modified so that the image is processed in the best way possible.

In addition, in this tab, the user has the possibility of starting the Webcam attached to the computer or integrated in the laptop. By pressing the Start button, the user can select the video source, in case there is more than one webcam attached to the computer on which the application is installed. Moreover, this choice can be made while the video is displayed, by pressing the Video Source button. The webcam source is used for instant screenshots.

The thresholds for the colors white, black and yellow are useful for the supervisor to improve the processed image, by modifying these thresholds according to the colors found in the original image. Different images can be better transformed with different thresholds.

## 6.6 Image processing for color transformation

*Fig 6.8 Image Conversion. Original left. Processed Right*

An important aspect is the conversion of RGB Images or Web Camera frames [86] to the 6 color set proposed above. This is done by evaluating the similarity between every pixel in the image with one of the 6 basic colors, followed by the conversion of the pixel to the basic color.

Each pixel has 3 components: Red, Green and Blue. In the first step of the image processing algorithm we used a standard 3-byte RGB conversion method. In the second step we decided that cyan is close to blue and purple to red and this assumption helped us to reduce the number of colors from 8 (3-byte RGB ) to 6 . Using this type of approach we decided if the pixel is more similar to red, green, blue or yellow.

Furthermore, a comparison was made between each component and two set values, 80 and 180 (obtained through testing), to check if the pixel is more similar to white or respectively black. After the testing is done by the algorithm is finished, the pixel is transformed in one of the 6 basic colors. In Fig 6.8 is presented a famous painting that is processed using the described method.

## 6.7 Conclusions

The haptic system that was designed presents a new way of transforming images and video screenshots into vibrations using an Xbox gamepad controller. This method proved to be promising giving the fact that it was easily accepted by volunteers (chapter 7) due to an easy interaction between the user and the vibration tool. A static image, a picture, a screen shot or a web cam video frame is converted into a six color scheme, on purpose to be explored by visually impaired people using a mouse, thus generating different levels of vibration.

The presented system offers the following functionalities:

- The possibility of learning a certain association between a vibration and a color, with the purpose of using this information for the color perception of an image or a video.
- The possibility of configuring two vibration intensities when one of the controller's triggers is pressed. Such thing allows a fast learning process.
- The possibility of testing if the associations were accurately learned by pressing one of the colors so that the controller vibrates with the intensity associated with that color.
- Displaying in parallel boxes the input and output of the processing
- The capability of configuring different parameters for a better image processing, according to the colors found in the original image and their correlation to real life objects.
- The possibility of moving the mouse over the processed image or video, so that the visually impaired person can get a tactile feedback. This way, with the proper training the user can understand what shapes and colors are found in the source.

### 6.7.1 Purpose of the application

The purpose of developing such an application was strictly experimental. The rudimentary image processing algorithms can be enhanced with far better versions described in detail in state of the art papers [89]. The user interface is elementary but with plenty of features to serve a trained supervisor within the experimental stage. The implementation and software engineering structure are based on *Forms* concepts but it can be adapted anytime to modern techniques. The application is far away from the alpha version but it highlights the fact that the proof of concept is worth all the attention. The experimental measurements and training (chapter 7) were put in practice using the Windows application on a touchscreen tablet PC and a regular notebook.

### 6.7.2 Encountered difficulties

Within the experiment stage, system development and implementation, several difficulties were encountered. Some of them are presented below:

- the documentation, the finding and the use of all the instruments that are necessary in order to install the XNA framework and for the coding of the Xbox controller are available only for paid courses;

- capturing the computer's webcam and display it in a pictureBox was realized by using a external reference class [86] that contains several pre-implemented methods useful for the manipulation of this input from device;
- The real-time processing of the video played from the webcam was a serious concern. The problem was solved by limiting the update function to a lower frame rate, a decent 10 frames/second.
- Setting the controller's vibration for a certain amount of time required the implementation of a method to call multiple times a standard XNA function to be able to achieve the desired vibration time.
- The processing of a single pixel and how the system should convert a specific color to one of the six colors. A borderline color like orange would be red or yellow? This was solved by adding extended configuration parameters for the supervisor so that he can see control the output image and adjust color conversion parameters according to his interpretations.

### 6.7.3 Future work

This research idea will be further studied in order to improve the learning process of visually impaired people

Some of the future research and implementation ideas are:

- Implementation of a method that allows the visually impaired person to navigate over the processed image, by using the controller's joystick. This will eliminate the use of the computer mouse and thus, there will be an easier interaction between the user and the application.
- The vibration generator classes and system must be adapted in using extended interfaces [72] so that it can integrate and work with other types of special controllers, game consoles and standard gamepads; this would make the concept accessible to everyone for a very low price;
- Currently the controller is wired, connected with an USB cable to the computer but in order to offer a higher degree of freedom it would be great if it could work wirelessly. Of course that Microsoft Xbox has cable free controllers, but those are not meant to be connected to a PC interface for development purposes. This improvement is conditioned by the release of an adapter [69] announced to be released by the end of 2015;
- Assigning a sound (recorded voice or various ding sounds) in the learning stage would probably increase the level of attention needed to interact with the system but for those who have a highly developed sound perception skill would make an important difference. In the perception stage normal sounds might be annoying but as state of the art research highlights [71], they can be replaced with binaural sounds [70] which are proved to be effective on lots of assistive tools for visually impaired people
- The experiment can be extended into a more precise direction to work in groups established by the nature and type of the disease or disorder. This way, the concept can be technically and haptically adapted to each of the group needs.

# 7 Description of the experiments

## 7.1 Volunteer meetings

During the development of the two original applications there were a total of 5 meetings with visually impaired volunteers. All those gatherings were hosted by the National Association of the Blind People in Romania / subsidiary Sibiu. This was a familiar environment for the subjects because they have monthly discussions here with friends and relatives. The meetings took place every Monday at a specific time because visually impaired people tend to be very organized persons.

The first meeting was an introduction session, where all the participants were informed about the following aspects:

- purpose of the research
- how they can contribute and how important their opinion is
- how to interact with touchscreen devices

Moreover, during this first encounter all the participants (13 volunteers) became familiar with tablets and asked numerous questions about new technologies, devices and assistive tools that address their needs.

During the second, third and fourth meetings, each one of the volunteers (between 4-6 volunteers/ meeting) offered important feedback related to:

- how they feel like during testing scenarios with specific tools
- how would they expect to interact with the device
- what mobile device are they using and why
- what's the most uncomfortable tool and what should we change

The fifth reunion was the most important one, because the application had all the tools ready and they could test all features. Also during this evaluation session each volunteer was tested individually, in a separate room and a performance review form was completed in order to register his results. All 12 persons, 10 volunteers, the director and secretary of the association (both of them also fully blind) spent about 6 hours together testing the tools and talking about future improvement ideas and other assistive tools.

All subjects had the same evaluation form completed by myself during the test and assisted by 2 supervisors. All used the same testing devices:

- Samsung Galaxy Tab (10 inch display) –touchscreen application – 3 available devices
- Microsoft Xbox Standard Gamepad –color perception application – 3 available devices

## 7.2 Evaluation form

During the final meeting, a form was completed for each candidate in order to measure his performance. The higher grades represent the best values.

The form consists of 5 groups of data:

- personal information
- visually impairment
- technologies
- performance using the developed visually impaired touchscreen application
- performance using the gamepad application for color perception

These are the entries from the testing form:

**Personal information**

1. How old are you?
2. What do you do for living / what is your current job?
3. Last graduated school?

**Visually impairment**

4. What are your visual deficiencies?
5. You were born with visual deficiencies? Yes / No.
6. What sense/senses are stronger? Hearing / Taste / Smell / Touch.

**Technologies**

7. Do you have a personal computer?  Yes / No.
8. Do you know what a smartphone is? Yes / No.
9. Do you own a smartphone or a tablet? Yes / No.
10. Do you know what Xbox or PlayStation is? Yes / No.
11. How much you do you enjoy modern technologies? On a scale from 1 to 5

**Performance using the developed visually impaired touchscreen application**

12. How easily he understands the text-to-speech explanations? On a scale from 1 to 5
13. Asks additional questions about using the tools? Yes / No.
14. Menu navigation skills, gestures, touches. On a scale from 1 to 5
15. Did he managed to complete the rectangle? No/ Beginner/ Medium/ Expert.
16. Did he managed to complete the circle? No/ Beginner/ Medium/ Expert.
17. Piano activity performance. On a scale from 1 to 5

**Performance using the gamepad application for color perception**

18. How easily he understands the concept? On a scale from 1 to 5.
19. During the experiment the subject is concentrating on vibration or on the sound produced by vibrating device? Sound / Vibration.
20. How fast the subject learns the differences between colors in the learning stage? On a scale from 1 to 5
21. Accuracy on first attempt to perceive colors? On a scale from 1 to 5
22. Accuracy on second attempt to perceive colors? On a scale from 1 to 5
23. Accuracy on third attempt to perceive colors? On a scale from 1 to 5

Observation: On the scale, 1 means performing bad, 5 means performing very good.

## 7.3 Raw results set

In the table below (Table 7.1) the information represents the raw data as it was recorded during the form completion.

| Q/S | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 56 | 49 | 38 | 52 | 24 | 37 | 19 | 61 | 21 | 42 | 49 | 45 |
| 2 | masseur | masseur | crafting | no job | actor | masseur | student | retired | student | no job | masseur | economist |
| 3 | univ. | high school | high school | high school | univ. | high school | high school | basic school | high school | high school | basic school | univ. |
| 4 | totally blind | legally blind | legally blind | color blind | legally blind | legally blind | legally blind | totally blind | legally blind | legally blind | low vision | color blind |
| 5 | yes | yes | no | yes | no | yes | no | yes | yes | no | yes | no |
| 6 | touch | touch | touch | hear | hear | taste | touch | touch | touch | smell | touch | hear |
| 7 | Yes | Yes | Yes | Yes | No | Yes | Yes | No | Yes | Yes | Yes | Yes |
| 8 | No | No | Yes | No | Yes | Yes | Yes | No | Yes | Yes | No | Yes |
| 9 | No | No | No | No | Yes | No | No | No | No | No | No | Yes |
| 10 | No | No | No | No | Yes | No | No | No | No | No | No | No |
| 11 | 2 | 3 | 1 | 2 | 5 | 3 | 2 | 5 | 3 | 1 | 4 | 5 |
| 12 | 5 | 5 | 5 | 4 | 5 | 3 | 5 | 5 | 5 | 5 | 4 | 5 |
| 13 | Yes | No | Yes | Yes | Yes | Yes | No | No | No | No | No | Yes |
| 14 | 4 | 2 | 3 | 5 | 5 | 3 | 2 | 3 | 4 | 3 | 1 | 5 |
| 15 | Beginner | Beginner | Beginner | Medium | Expert | Medium | Expert | Medium | Medium | Medium | Beginner | Expert |
| 16 | Medium | No | Beginner | Beginner | Expert | No | Expert | Beginner | Medium | Beginner | Beginner | Expert |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 17 | 5 | 5 | 2 | 5 | 4 | 1 | 3 | 5 | 3 | 3 | 4 | 5 |
| 18 | 5 | 1 | 5 | 4 | 5 | 5 | 5 | 3 | 3 | 5 | 4 | 5 |
| 19 | Vibration | Sound | Vibration | Vibration | Sound | Vibratio n | Vibratio n | Vibration | Vibration | Vibration | Vibration | Vibration |
| 20 | 5 | 2 | 4 | 5 | 5 | 5 | 2 | 5 | 5 | 3 | 2 | 5 |
| 21 | 4 | 1 | 1 | 1 | 4 | 1 | 2 | 1 | 1 | 1 | 2 | 4 |
| 22 | 4 | 2 | 1 | 2 | 5 | 3 | 2 | 5 | 3 | 3 | 4 | 5 |
| 23 | 5 | 2 | 2 | 2 | 5 | 5 | 2 | 4 | 4 | 2 | 2 | 5 |

*Table 7.1 Raw data with the form information*

## 7.4 Charts and statistics

According to the dataset (Table 7.1) containing all the recordings from the evaluation form, this experiment concludes the following charts and statistics:

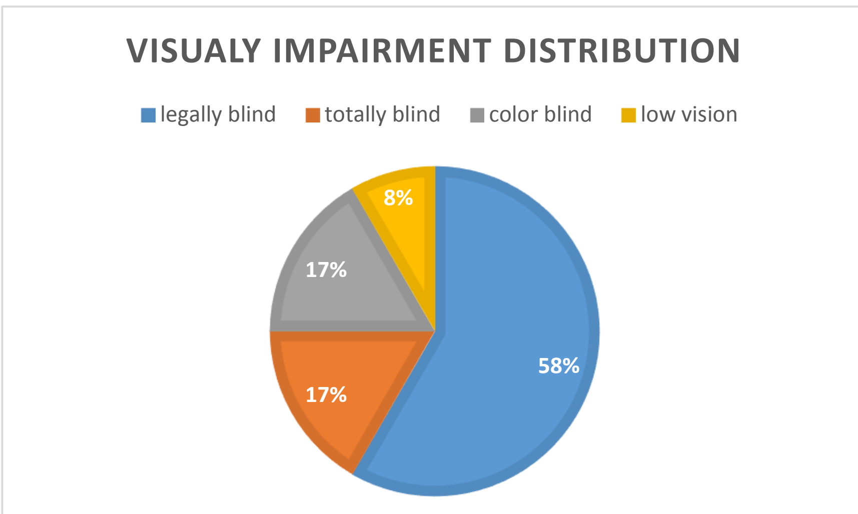


*Chart 7.1 Visually impairment distribution among the volunteers*

We can observe in Chart 7.1 that 58 % of the volunteers where classified as legally blind (less than 20/200 vision in their better eye, or a very narrow field of view, generally 20 degrees at its far-reaching point) and 17% as totally blind meaning that 75 % of the participants included in the experiment where suffering from severe eye problems.

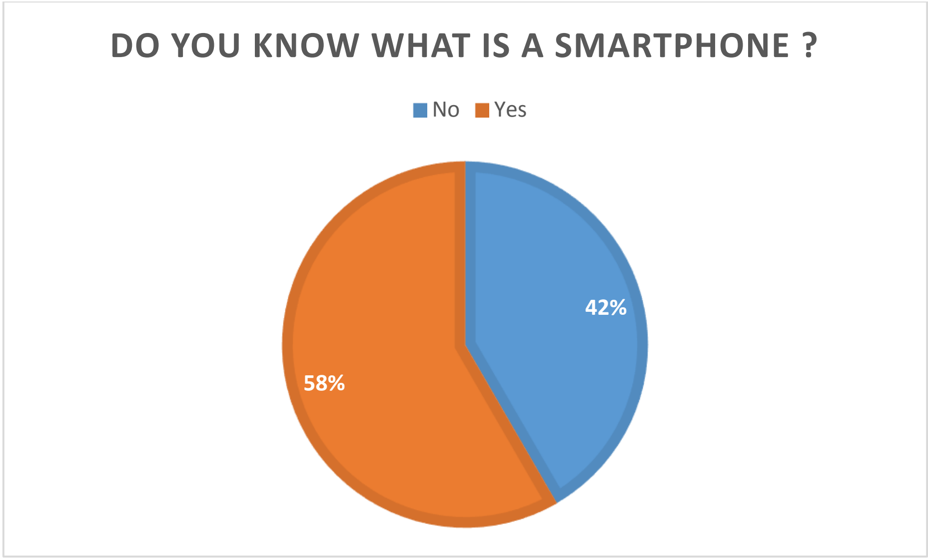


*Chart 7.2. Answer to the question: Do you know what a smartphone is?*

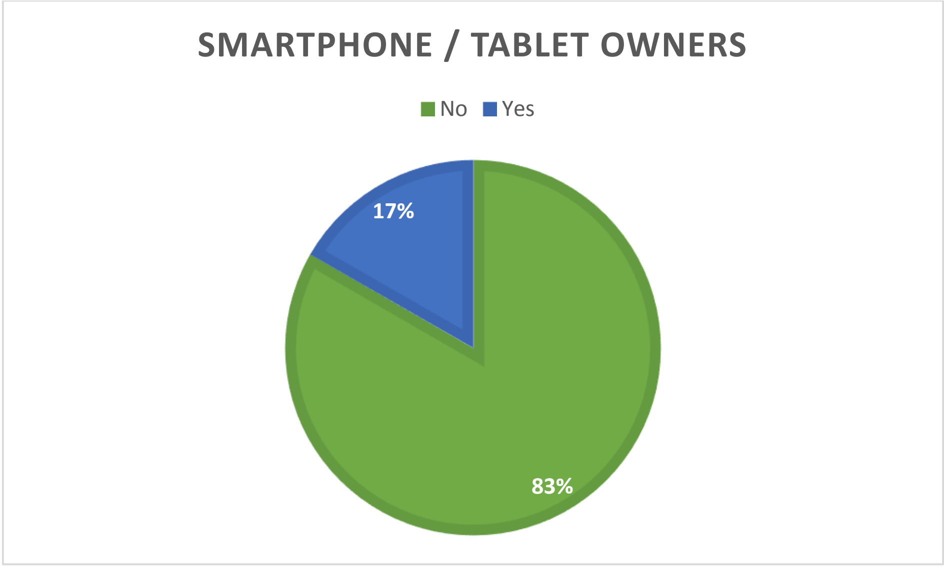


*Chart 7.3 Smartphone/Tablet owners among volunteers*

Having a look at charts 7.2 and 7.3 we can conclude that very few visually impaired people are benefiting from the amazing accessibility capabilities of modern touchscreen devices. A good method for improving this aspect would be to present them a lot of interesting tools and features so that they can see the advantages of purchasing such a device.

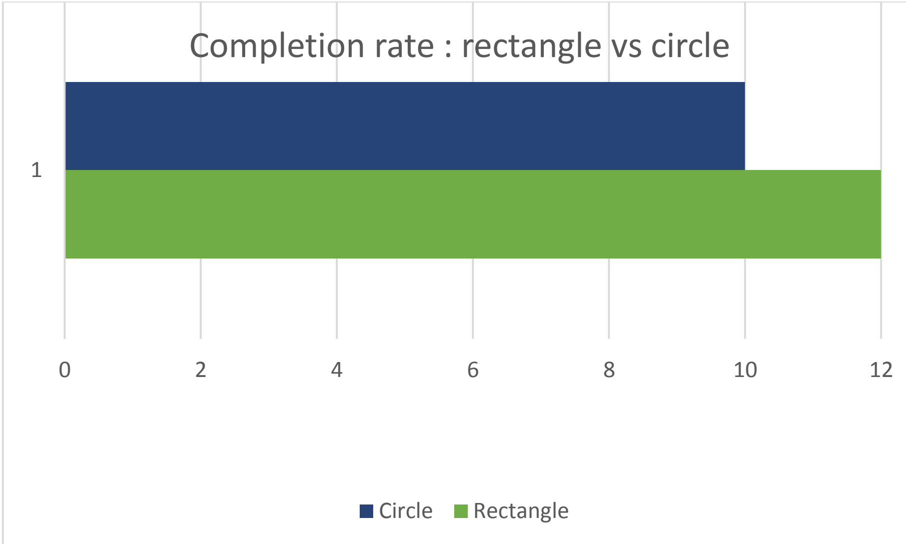


*Chart 7.4 Completion rate: rectangle tool vs circle tool for the touchscreen application*

Learning basic geometric shapes was one of the favorite tests among volunteers and if we were to measure which one is easier, according to Chart 7.2, the rectangle is easier to follow on touchscreen surfaces because all subjects managed to complete the form successfully.

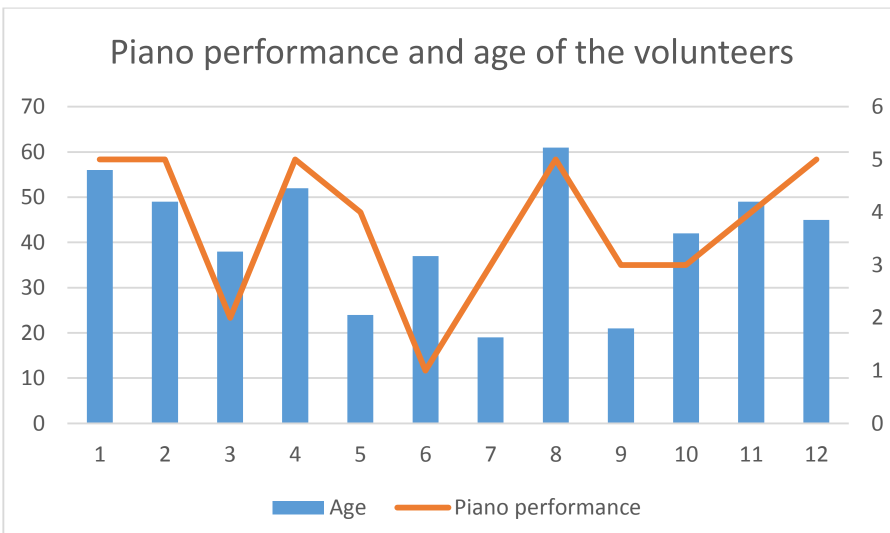


*Chart 7.5 Piano performance and age of the volunteers for the touchscreen application*

The piano tool is very difficult to use and requires high concentration and patience. A very interesting result is displayed in Chart 7.5. Two charts were overlapped, the age (left) of each volunteer (from 1 to 12) and performance for using the piano tool (right). A conclusion is that the piano performance seems to be somehow influenced by the age of the volunteers.

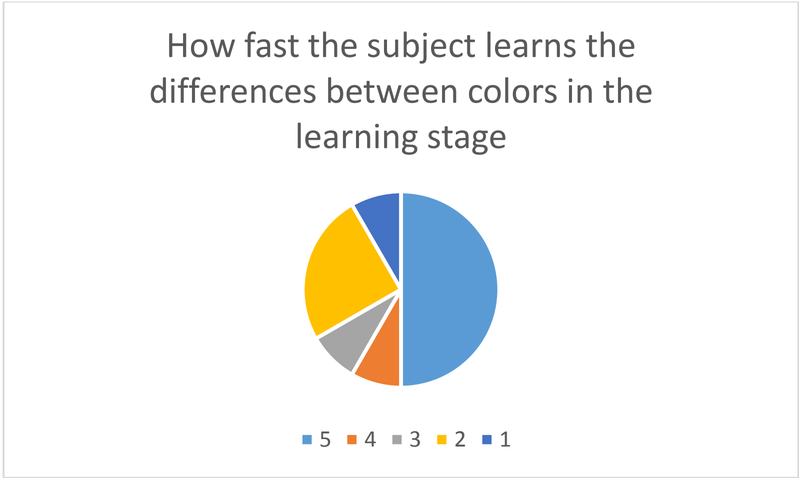


*Chart 7.6 Individual color perception accuracy using a gamepad*

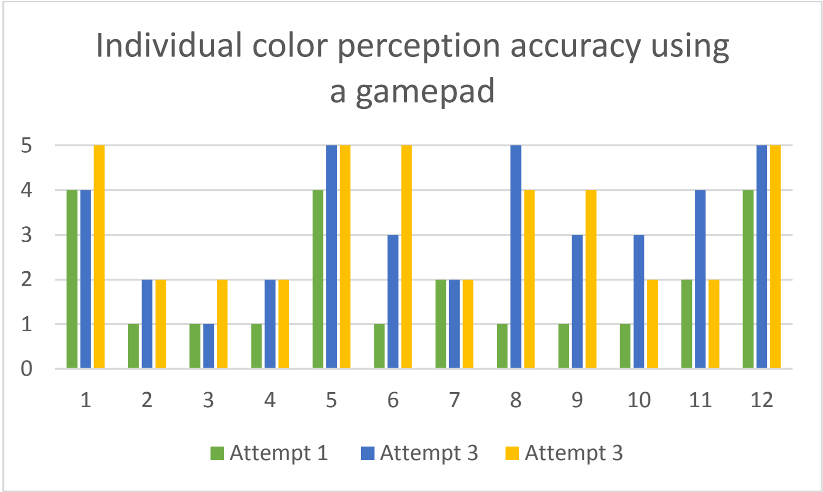


*Chart 7.7 Individual color perception accuracy using a gamepad*

Perceiving colors haptically using a gamepad was a bold approach that proved to be efficient. As Chart 7.6 reveals, more than 50 % of the subjects managed to learn very fast (graded 4 and 5) the difference between colors. Another interesting result displayed in Chart 7.7, is that from attempt 1 to attempt 3 almost all the subjects managed to improve the detection rate which concludes that this approach is worthy to be further studied.

The charts and statistics presented in this chapter reflect experimental information specific to the testing environment and availability of volunteers. The outcome cannot be observed as generally valid until an extended research will be made on a larger group of people.

# 8 Conclusions

## 8.1 Important aspects

The most important aspect of this thesis was the interaction of visually impaired people, regardless of the severity of symptoms, with modern devices. Contemporary technology holds the necessary features to make their integration easier. They should adapt to the use of these devices as their price falls rhythmically and they could become indispensable assistive tools.

The use of combined methods (haptic, auditory and auditory/haptic) to convey visual information is relatively recent in the scientific literature, but it will enjoy an ascending trend in the next years. The explanation lies within the obvious benefits of associating all possible communication and interaction channels with hi-tech tools and Internet of Things concepts. These 2 models presented in the chapters above will contribute to the strategy of a bigger project called Sound of Vision [95]. This program studies the development of assistive electronic devices that can address one of the major problems faced by the visually handicapped people - assistance throughout their daily life, autonomy, mobility and prevention of dangerous situations.

To strengthen the conclusions, I truly believe that this research material is an important component that merges Human Computer Interaction, eHealth and eLearning in the context of global technological ascendance, which is why if the analysis continues, in the next few years it might have the ability to generate life changing effects for people with vision problems.

## 8.2 Original contributions

- (Chapter 3) An analysis regarding existing research models, concepts, tools, applications, and end user products available for touchscreen applications and other devices used as assistive tools for visually impaired people; reviews, conclusions and improvement suggestions were published in [44], [97], [98], [55], [99], [101].
- (Chapter 4) An original application that allows learning basic geometric shapes through touchscreen devices was developed and the results of using it with visually impaired people were published in the following [100].
- (Chapter 4) A user interface design methodology, technical details and advices for implementing touchscreen based application on Android devices for visually impaired people were published in [44], [100].
- (Chapter 5) An analysis regarding existing methods, gadgets and innovative devices that contribute the process of perceiving colors haptically; reviews, conclusions and improvement suggestions were published in [57], [99].
- (Chapter 6) An original architecture consisting of a Xbox gamepad and an experimental application that aims to learn  visually impaired people to perceive colors in an distinctive approach; results and conclusions published in [57], [96];
- (Chapter 7) Experiments with visually impaired volunteers using educational and assistive IT tools for sighted people; results will be published soon.

# 9 Published papers

During the doctoral stage I have published the main results in 19 scientific publications, as follows

- 4 journal publications
- 12 conference publications
- 3 books

Some papers are not reflected directly in the thesis but are related to the research area of the thesis.

### 9.1.1 Journals

1) Butean A., Bălan O., *Region Detection and Depth Labeling on Kinect Streams*, Bulletin of the Polytechnic Institute of Iasi, Published by Gheorghe Asachi" Technical University of Iaşi, ISSN 1223-8139, Tom. LX (LXIV), Fasc. 3-4, pp. 97-106, 2014 (BDI)

2) Bălan O., Butean A., *Designing 3D Audio and Haptic Interfaces for Training the Sound Localization Ability of the Visually Impaired People*, Bulletin of the Polytechnic Institute of Iasi, Published by Gheorghe Asachi" Technical University of Iaşi, ISSN 1223-8139, Tom. LX (LXIV), Fasc. 3-4,
pp. 87-96, 2014 (BDI)

3) Butean A., Troancă B, Bălan O., Moldoveanu F., Moldoveanu A., *Applications on touchscreen mobile devices for the visually impaired people*, Romanian Journal of Human - Computer Interaction, Published by MATRIX ROM, ISSN 1843-4460, 2015 (BDI)

4) Bălan O., Moldoveanu A., Moldoveanu F., Butean A., *Spatial Sound Based System For Improving Orientation And Mobility Skills In The Absence Of Sight*, Scientific Bulletin by University Politehnica of Bucharest (BDI)

### 9.1.2 Conferences

1) Bălan O., Moldoveanu A., Butean A., Moldoveanu F., Negoi I., *Comparative Research on Sound Localization Accuracy in the Free-Field and Virtual Auditory Displays*, Procedings of the 11th International Scientific Conference eLearning and Software for Education, Bucharest, April 23-24, Vol. 1, ISSN: 2343–7669, ISSN–L: 2066–026X, 2015 (ISI)

2) Stancu M., Popa E., Butean A., *An Approach To Improve Elearning Platforms Accessibility*, Procedings of the 11th International Scientific Conference eLearning and Software for Education, Bucharest, April 23-24, Vol. 1, ISSN: 2343–7669, ISSN–L: 2066–026X, 2015 (ISI)

3) Butean A., Moldoveanu A., Morar A., *From Classic Math School Books To Interactive Gamified Elearning*, Procedings of the 11th International Scientific Conference eLearning and Software for Education, Bucharest, April 23-24, Vol. 1, ISSN: 2343–7669, ISSN–L: 2066–026X, 2015 (ISI)

4) Butean A., Bălan O., Moldoveanu A., Moldoveanu F., *ICT Evolutions Supporting The Development Of Assistive Systems For Visually Impaired People*, WPA Congress, Bucharest, 2015 (BDI)

5) Harutyunyan P., Butean A., Morar A., Moldoveanu A., Moldoveanu F., *Improving Ergonomics For Sedentary Jobs Through Bodyposture Monitoring*, Procedings of the 11th International Scientific Conference eLearning and Software for Education, Bucharest, April 23-24, Vol. 1, ISSN: 2343–7669, ISSN–L: 2066–026X, 2015 (ISI)

6) Butean A., Bălan O., Moldoveanu A., Moldoveanu F., *Touchscreen Based Audio and Vibro-Tactile Applications as Assistive Systems for People Suffering from Eye Disorders*, The 22nd International Congress on Sound and Vibration, Florence, Italy, 12-16 July, 2015 (BDI)

7) Bălan O., Butean A., Moldoveanu A., Moldoveanu F., *Auditory and Haptic Spatial Cognitive Representation in the Case of the Visually Impaired People*, The 22nd International Congress on Sound and Vibration, Florence, Italy, 12-16 July 2015 (BDI)

8) Butean A., David A., Buduleci C., Daian A., *Auxilum Medicine: A Cloud Based Platform For Real-time Monitoring Medical Devices*, Procedings of the 20th International Conference on Control Systems and Computer Science, Bucharest, May 27-29, 2015 (ISI)

9) Trifanica V., Butean A., Moldoveanu A., Butean D., *Gamepad vibration methods to help blind people perceive colors*, the 12th edition of Romanian Human-Computer Interaction Conference 2015, 24-25 September 2015, Bucharest. (ISI)

10) Troanca B., Butean A., Moldoveanu A., Bălan O., *Introducing basic geometric shapes to visually impaired people using a mobile app*, The 12th edition of Romanian Human-Computer Interaction Conference 2015,24-25 September 2015, Bucharest. (ISI)

11) Strimbeanu P, Butean A., Moldoveanu F., *An approach for detecting ID frauds in a traditional voting system using a smartphone stand*, the 12th edition of Romanian Human-Computer Interaction Conference 2015, 24-25 September 2015, Bucharest. (ISI)

12) Bălan O., Moldoveanu A., Moldoveanu F., Butean A., *Developing a navigational 3D audio game with hierarchical levels of difficulty for the visually impaired players*, The 12th edition of Romanian Human-Computer Interaction Conference 2015, 24-25 September 2015, Bucharest. (ISI)

### 9.1.3 Books

1) Cruceat Alin, Butean Diana, Cioca Lucian, Butean Alexandru, *Detectarea poziției corporale corecte utilizând camera cu senzor de adâncime. Aplicație software experimentală*, ISBN: 978-606-12-1082-4, Lucian Blaga University of Sibiu Publishing House ( scheduled to be printed in October 2015)
2) Trifanica Vlad, Butean Alexandru, *Sistem asistiv pentru persoanele cu probleme de vedere pentru perceperea culorilor prin vibrație folosind un gamepad*, ISBN: 978-606-12-1083-1, Lucian Blaga University of Sibiu Publishing House ( scheduled to be printed in October 2015)
3) Troanca Bogdan, Butean Alexandru, Metodologia de implementare a unei aplicații pentru învățarea și ghidarea persoanelor nevăzătoare folosind tehnologii pentru dispoztive touchscreen, ISBN: 978-606-12-1083-1, Lucian Blaga University of Sibiu Publishing House ( scheduled to be printed in October 2015)

# 10 References

[1] Royal Institute for Deaf and Blind People. Online resource accessed in August 2015, available at: http://www.ridbc.org.au/blindness

[2] America Foundation for the Blind, Learning about blindness. Online resource accessed in August 2015, available at:: http://www.afb.org/info/living-with-vision-loss/for-job-seekers/for-employers/visual-impairment-and-your-current-workforce/learning-about-blindness/12345

[3] Maberley, DA; Hollands, H; Chuo, J; Tam, G; Konkal, J; Roesch, M; Veselinovic, A; Witzigmann, M; Bassett, K (March 2006). The prevalence of low vision and blindness in Canada. Eye Nature 20 (3): pages 341–346, 2006

[4] Centers for disease control and prevention, Gateway to Health Communication & Social Marketing. Online resource accessed in August 2015, available at: http://www.cdc.gov/healthcommunication/ToolsTemplates/EntertainmentEd/Tips/Blindness.html

[5] World Health Organization, Global Data of Visual Impairments, 2010. Online resource accessed in August 2015, available at: http://www.who.int/blindness/GLOBALDATAFINALforweb.pdf?ua=1

[6] Questions & Answers about Blindness and Vision Impairments in the Workplace and the Americans with Disabilities Act (ADA). Online resource accessed in August 2015, available at: http://www.eeoc.gov/eeoc/publications/qa_vision.cfm

[7] Teens Health. Online resource accessed in August 2015, available at: http://kidshealth.org/teen/diseases_conditions/sight/visual_impairment.html

[8] America Foundation for the Blind, Facts and Figures on Adults with Vision Loss, Updated May 2014. Online resource accessed in August 2015, available at: http://www.afb.org/info/blindness-statistics/adults/facts-and-figures/235

[9] The voice of blind and partially sighted people in Europe, Facts, figures and definitions concerning blindness and sight loss. Online resource accessed in August 2015, available at: http://www.euroblind.org/resources/information/

[10] The International Agency for the Prevention of Blindness, Global action plan. Online resource accessed in August 2015, available at: http://www.iapb.org/advocacy/who-action-plan

[11] Sound of Vision, Horizon 2020 Project Proposal

[12] Workplace prejudice keeps blind people out of employment. Online resource accessed in August 2015, available at: http://www.euractiv.com/specialreport-europe-blind-spot/workplace-prejudice-keeps-blind-news-530904

[13] Disabled World, Vision Disability: Types, News & Information. Online resource accessed in August 2015, available at: http://www.disabled-world.com/disability/types/vision/

[14] Bright Hub Education, Common Types of Visual Impairments. Online resource accessed in August 2015, available at: http://www.brighthubeducation.com/special-ed-visual-impairments/35103-common-types-of-visual-impairment-in-students/

[15] The Scrips Research Institute. Blindness and Vision Loss Research. Online resource accessed in August 2015, available at: http://www.scripps.edu/discover/blindness.html

[16] Sense chartity, about deafblindness. Online resource accessed in August 2015, available at: https://www.sense.org.uk/content/about-deafblindness

[17] Deafblind education, Frequently Asked Questions about Deafblindness. Online resource accessed in August 2015, available at: http://www.deafblindinfo.org/faq.html

[18] Provincial Outreach Program for Students with Deafblindness. Online resource accessed in August 2015, available at: http://popdb.sd38.bc.ca/Categories_of_Deafblindness

[19] World Health Organization. Socio economic aspects of blindness and visual impairment. Online resource accessed in August 2015, available at: http://www.who.int/blindness/economy/en/

[20] Brown R.L, Barret A.E, Visual Impairment and Quality of Life among Older Adults: An Examination of Explanations for the Relationship. Online resource accessed in August 2015, available at: http://psychsocgerontology.oxfordjournals.org/content/66B/3/364.full

[21] United States National Eye Institute. Vision Impairment Tables. Online resource accessed in August 2015, available at: https://nei.nih.gov/eyedata/vision_impaired/tables

[22] World Health Organization, Visual impairment and blindness, Fact Sheet N282, Updated August 2014. Online resource accessed in August 2015, available at: http://www.who.int/mediacentre/factsheets/fs282/en/

[23] Dicromacy. Online resource accessed in August 2015, available at: http://www.mecourse.com/landinig/software/dichromacy/dichromacy.html

[24] Laservue Eye Center, How the Eye works. Online resource accessed in August 2015, available at: http://www.laservue.com/about-us/how-the-eye-works

[25] United States National Eye Institute. Vision Impairment. Online resource accessed in August 2015, available at: https://nei.nih.gov/eyedata/vision_impaired

[26] Assistive Technology for the Blind and Visually Impaired | HIMS Inc. Braille Sense U2 Communicator. Online resource accessed in August 2015, available at: http://hims-inc.com/products/braille-sense-u2-communicator/

[27] Jacobson, R.D. Cognitive Mapping Without Sight: Four Preliminary Studies of Spatial Hearing, Journal of Environmental Psychology, 18(3), pages 289-305, 1998

[28] Bujacz, M., Pec, M., Skulimowski, P., Strumillo, P., Materka, A. Sonification of 3D Scenes in an Electronic Travel Aid for the Blind, Advances in Sound Localization, Dr. Pawel Strumillo (Ed.),ISBN: 978-953-307-224-1, InTech.Migdalovici, M., Sireteanu, T. and Videa, E. M. Control of Vibration of Transmission Lines, International Journal of Acoustics and Vibration,15 (2), pages 65–71, 2010

[29] Schloerb, D., Lahav, O., Desloge. J.G., Srinivasan, M.A. BlindAid: Virtual Environment System for Self-Reliant Trip Planning and Orientation and Mobility Training, IEEE Haptics, Symposium, Waltham, USA, pages 363 - 370, 2010

[30] Lahav, O., Mioduser, D. Blind Person's Acquisition of Spatial Cognitive Mapping and Orientation Skills Supported by Virtual Environment, International Journal on Disability and Human Development, 4(3), pages 231-238, 2011

[31] Stiles, N.R.B., Shimojo S. Sensory Substitution: A New Perceptual Experience, Chapter 43 in The Oxford Handbook of Perceptual Organization, Johan Wagemans, Ed., Oxford University Press, New York, (In Press), 2014

[32] Ortiz, T., Poch, J., Santos, J.M., et al. Recruitment of occipital cortex during sensory substitution training linked to subjective experience of seeing in people with blindness, PLoS, DOI: 10.1371/journal.pone.0023264, 2011

[33] Arno, P., De Volder, A.G., Vanlierde, A., et al. Occipital activation by pattern recognition in the early blind using auditory substitution for vision, Neuroimage, 13, pages 632-645, 2001

[34] Amedi, A., Stern, W.M., Camprodon, J.A., et al. Shape conveyed by visual-to-auditory sensory substitution activates the lateral occipital complex, Nature Neuroscience, 10, pages 687-689, 2007

[35] Picinali, L., Afonso, A., Denis, M., Katz, B.F.G. Exploration of Architectural Spaces by Blind People Using Auditory Virtual Reality for the Construction of Spatial Knowledge, International Journal on Human-Computer Studies, 72(4), pages 393-407, 2014

[36] Afonso, A., Katz, B.F.G., Blum, A., Jacquemin, C., Denis, M. A Study of Spatial Cognition in an Immersive Virtual Audio Environment: Comparing Blind and Blindfolded Individuals, Proceedings of the 11th Meeting of the International Conference on Auditory Display, Limerick, Ireland, 6-9 July, 2005

[37] Afonso, A., Blum, A., Katz, B.F.G., Tarroux, P. Structural Properties of Spatial Representations in Blind People: Scanning Images Constructed from Haptic Exploration or from Locomotion in a 3-D Virtual Environment, Memory&Cognition, pages 591-604, 2010

[38] Noordzij, M.L., Zuidhoek, S., Postma, A. The Influence of Visual Experience on the Ability to Form Spatial Mental Models Based on Route and Survey Descriptions, Cognition, 100(2), 321-342, (2006).

[39] Klatzky, R. L., Golledge, R. G., Loomis, J. M., Cicinelli, J. G., & Pellegrino, J. W. Performance of blind and sighted persons on spatial tasks, Journal of Visual Impairment & Blindness, 89, 70–82, (1995).

[40] Papadopoulus, K., Papadimitriou, K., Koutsoklenis, A. The Role of Auditory Cues in the Spatial Knowledge of Blind Individuals, International Journal of Special Education, 4(2), pages 169-180, 2012

[41] Schafer, R. M. The soundscape: Our sonic environment and the tuning of the world, Rochester, VT: Destiny Books, 1994

[42] Truax, B. Handbook for acoustic ecology, Burnaby, B.C.: Cambridge Street Records, 1999

[43] Bălan O., Butean A., Moldoveanu A., Moldoveanu F., Auditory and Haptic Spatial Cognitive Representation in the Case of the Visually Impaired People, The 22nd International Congress on Sound and Vibration, Florence, Italy, 12-16 July 2015

[44] Troanca Bogdan, Butean Alexandru, Metodologia de implementare a unei aplicații pentru învățarea și ghidarea persoanelor nevăzătoare folosind tehnologii pentru dispoztive touchscreen, ISBN: 978-606-12-1083-1, Lucian Blaga University of Sibiu Publishing House (scheduled to be printed on paper in October 2015)

[45] American Foundation for the blind, Assistive Technology. Online resource accessed in August 2015, available at: http://www.afb.org/info/living-with-vision-loss/using-technology/assistive-technology/123

[46] American Foundation for the Blind, Educating Students with Visual Impairments for Inclusion in Society. Online resource accessed in August 2015, available at: http://www.afb.org/info/programs-and-services/professional-development/teachers/inclusive-education/1235

[47] Enable Magazine, Disability News, "Multi-sensory photography by blind and visually impaired people" article from 17 June 2015. Online resource accessed in August 2015, available at: http://enablemagazine.co.uk/multi-sensory-photography-by-blind-and-visually-impaired-people/

[48] Buzzi M. C., Buzzi M., Leporini B., Paratore M. T., Vibro-Tactile Enrichment Improves Blind User Interaction with Mobile Touchscreens, în Paula Kotzé; Gary Marsden; Gitte Lindgaard; Janet Wesson & Marco Winckler, ed., 'INTERACT (1)' , Springer, pages 641-648, 2013

[49] Oh U., Kane S.K., Findlater L., Follow That Sound: Using Sonification and Corrective Verbal Feedback to Teach Touchscreen Gestures, ACM SIGACCESS Conference on Computers and Accessibility, ISBN: 978-1-4503-2405-2, Article Nr 13, 2013

[50] Rafael I., Duarte L., Carriço L., Guerreiro T.J.V.,Towards ubiquitous awareness tools for blind people, BCS HCI '13, Article Nr. 38, 2013

[51] Zimmermann S., Rümelin S., Butz A., I Feel it în my Fingers: Haptic Guidance on Touch Surfaces, Proc .TEI ’14, ACM Press, Pages 9-12, 2013

[52] Adams D., Kurniawan S., A blind-friendly photography application for smartphones, ACM SIGACCESS Accessibility and Computing, 108, pages 12-15, 2014

[53] Buzzi M.C., Buzzi M., Leporini B., Trujillo A., Designing a text entry multimodal keypad for blind users of touchscreen mobile phones, Proceedings of the 16th International ACM SIGACCESS Conference on Computers & Accessibility, pages 131-136, 2014

[54] Gupta A., Balram N., Objective comparisons between gesture and exploration based touchscreen keyboards for the blind, Proceedings of the 11th Asia Pacific Conference on Computer Human Interaction, pages 150-155, 2013

[55] Butean A., Troancă B, Bălan O., Moldoveanu F., Moldoveanu A., Applications on touchscreen mobile devices for the visually impaired people, Romanian Journal of Human - Computer Interaction, Published by MATRIX ROM, ISSN 1843-4460, 2015

[56] Gunther E., Skinscape: A Tool for Composition in the Tactile Modality, Master Disertation at Massachusetts Institute of Technology, Masters of Engineering, 2011

[57] Trifanica Vlad, Butean Alexandru, Sistem asistiv pentru persoanele cu probleme de vedere pentru perceperea culorilor prin vibrație folosind un gamepad, ISBN: 978-606-12-1083-1, Lucian Blaga University of Sibiu Publishing House (scheduled to be printed in October 2015)

[58] Moll J., Pysander E-L. S., “A haptic tool for group work on geometrical concepts engaging blind and sighted pupils”, în ACM Transaction on Accessible Computing (TACCESS), Volume 4 Issue 4, Article No. 14, 2013

[59] Burch D.S., Pawluk D. T. V., “A cheap, portable haptic device for a method to relay 2-D texture-enriched graphical information to individuals who are visually impaired", în Assets '09 Proceedings of the 11th international ACM SIGACCESS conference on Computers and accessibility, pages 215-216, 2009

[60] Kahol K., French J., Bratton L., Panchanathan S., “Learning and Perceiving Colors Haptically”, în Assets ’06 Proceedings of the 8th international ACM SIGACCESS conference on Computers and accessibility, pages 173-180

[61] Hribar V. E., Pawluk D. T. V., “A tactile-thermal display for haptic exploration of virtual paintings”, în Assets '11 The proceedings of the 13th international ACM SIGACCESS conference on Computers and accessibility, pages 221-222

[62] Headley P. C., Pawluk D. T. V., “A multimodal, computer-based drawing system for persons who are blind and visually impaired”, în Assets ’10 Proceedings of the 12th international ACM SIGACCESS conference on Computers and accessibility, pages 229-230, 2010

[63] Kuber R., Yu W., McAllister G., “Towards developing assistive haptic feedback for visually impaired internet users”, în CHI ’07 Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, pages 1525-1534, 2007

[64] Montagu A., Touching: The Human Significance of the Skin, Book published by Columbia University Press, New York, 1971

[65] Van Erp J. B. F., Guidelines for the use of active vibro-tactile displays în human-computer interaction, Proceedings of Eurohaptics 2002, Edinburgh, UK, pp 18-22, University of Edinburgh, 2002

[66] Brewster S., Brown L.M., Tactons: Structured Tactile Messages for Non-Visual Information Display, Proc. Fifth Australasian User Interface Conference (AUIC2004), Dunedin, New Zealand. CRPIT, 28. Cockburn, A., Ed. ACS. pages 15-23, 2004

[67] Kurze M., Rendering drawings for interactive haptic perception, Proceedings of ACM CHI'97, Atlanta, GA, pages 423-430, ACM Press, Addison-Wesley, 1997

[68] Gunther E., Davenport G., O'Modhrain S., Cutaneous Grooves: Composing for the Sense of Touch, Proceedings of Conference on New Instruments for Musical Expression, Dublin, IR, pages 1-6, 2002

[69] The Verge, Xbox wireless adapter is perfect for using your controller on a Windows 10 PC. Online resource accessed in August 2015, available at: http://www.theverge.com/2015/6/9/8751481/25-xbox-wireless-adapter-is-perfect-for-using-your-controller-on-a

[70] Delic V., Sedlar N., Stereo presentation and binaural localization in a memory game for the visually impaired, COST'09, ISBN:3-642-12396-1 978-3-642-12396-2, Pages 354-363, 2009

[71] Kortum P., HCI Beyond the GUI: Design for Haptic, Speech, Olfactory, and Other Nontraditional Interfaces, Morgan Kaufmann Publishers Inc. ISBN: 9780123740175, 2008

[72] DirectXTK. Online resource accessed in August 2015, available at: https://github.com/Microsoft/DirectXTK/wiki/DirectXTK

[73] Android developer, layouts. Online resource accessed in August 2015, available at: http://developer.android.com/guide/topics/ui/declaring-layout.html

[74] Nisha K.K., Pruthvi H.R., Hadimani S. N., Reddy Mohana G.R., Ashwin T.S., Domanal S., An Android GPS-Based Navigation Application For Blind, VINCI’14, pp. 240, 2014

[75] Chiti S., Leoporini B., Accessibility of android-based mobile devices: a prototype to investigate interaction with blind users, ICCHP'12, ISBN: 978-3-642-31533-6, Pages 607-614, 2012

[76] Skrodzka E., Furmann A.,Bogusz-Witczak E., Active And Passive Auditory Training For Visually Handicapped Young Persons , The 22nd International Congress on Sound and Vibration, Florence, Italy, 12-16 July, 2015

[77] Best Start: Ontario's Maternal, Newborn and Early Child Development Resource Centre, A Booklet for Parents – Learning to Play and Playing to Learn: Getting Ready for School, November 2013, Online resource accessed in August 2015, available at: http://www.beststart.org/resources/hlthy_chld_dev/school_readiness_ENG_Nov2013_blur.pdf

[78] Wolford J., Nielsen: 70% Of Kids In Tablet-Owning Households Use Them. Online resource accessed in August 2015, available at: http://www.webpronews.com/nielsen-tablets-kids-2012-02

[79] Younger children turn from phones to tablets. Online resource accessed in August 2015, available at: http://media.ofcom.org.uk/news/2013/younger-children-turn-from-phones-to-tablets/

[80] Google Text-to-Speech Engine. Online resource accessed in August 2015, available at: https://goo.gl/TwE0Id

[81] Butean A., Bălan O., Moldoveanu A., Moldoveanu F., Touchscreen Based Audio and Vibro-Tactile Applications as Assistive Systems for People Suffering from Eye Disorders, The 22nd International Congress on Sound and Vibration, Florence, Italy, 12-16 July, 2015

[82] IVONA Text-to-speech. Online resource accessed in August 2015, available at: https://www.ivona.com/

[83] IVONA Text-to-speech for Android devices. Online resource accessed in August 2015, available at: https://play.google.com/store/apps/details?id=com.ivona.tts

[84] Georgiephone, Smartphone Android apps for blind people. Online resource accessed in August 2015, available at: http://www.georgiephone.com/

[85] Senses in the dark. Sense of touch. Online resource accessed in August 2015, available at: http://www.seeinginthedark.eu/senses-in-the-dark/sense-of-touch/

[86] Webcam Class created by Pongsakorn Poosankamva. Online resource accessed in August 2015, available at: http://easywebcam.codeplex.com/

[87] The importance of color in marketing. Online resource accessed in August 2015, available at: https://www.nuvonium.com/blog/view/the-importance-of-color-in-marketing

[88] Color Matters. Online resource accessed in August 2015, available at: http://www.colormatters.com/

[89] Reinhard E., Ward G., Johnson G., Color imaging, SIGGRAPH '09, Article No. 9 , 2009

[90] Global shipment forecast for touch-screen displays from 2012 to 2016. Online resource accessed in August 2015, available at: http://www.statista.com/statistics/259983/global-shipment-forecast-for-touch-screen-displays/

[91] Butean A., Moldoveanu A., Morar A., *From Classic Math School Books To Interactive Gamified Elearning*, Procedings of the 11th International Scientific Conference eLearning and Software for Education, Bucharest, April 23-24, Vol. 1, ISSN: 2343–7669, ISSN–L: 2066–026X, 2015 (ISI)

[92] O'Connor A., Really? The Brain Gets rewired if one of the Senses Is lost, New York Times. Online resource accessed in August 2015, available at: http://goo.gl/TdIcPq

[93] Suggested Teaching Strategies: blind and visually impaired students – Newcastle University. Online resource accessed in August 2015, available at: http://goo.gl/SBi8fM

[94] Sound of Vision. Online resource accessed in August 2015, available at: http://www.soundofvision.net/

[95] Stancu M., Popa E., Butean A., *An Approach To Improve Elearning Platforms Accessibility*, Procedings of the 11th International Scientific Conference eLearning and Software for Education, Bucharest, April 23-24, Vol. 1, ISSN: 2343–7669, ISSN–L: 2066–026X, 2015

[96] Trifanica V., Butean A., Moldoveanu A., Butean D., *Gamepad vibration methods to help blind people perceive colors*, the 12th edition of Romanian Human-Computer Interaction Conference 2015, 24-25 September 2015, Bucharest.

[97] Troanca B., Butean A., Moldoveanu A., Bălan O., *Introducing basic geometric shapes to visually impaired people using a mobile app*, The 12th edition of Romanian Human-Computer Interaction Conference 2015,24-25 September 2015, Bucharest. (ISI)

[98] Bălan O., Moldoveanu A., Moldoveanu F., Butean A., *Spatial Sound Based System For Improving Orientation And Mobility Skills In The Absence Of Sight*, Scientific Bulletin by University Politehnica of Bucharest, 2015

[99] Butean A., Bălan O., Moldoveanu A., Moldoveanu F., ICT Evolutions Supporting The Development Of Assistive Systems For Visually Impaired People, WPA Congress, Bucharest, 2015

[100] Troanca B., Butean A., Moldoveanu A., Bălan O., *Introducing basic geometric shapes to visually impaired people using a mobile app,* The 12th edition of Romanian Human-Computer Interaction Conference 2015, Bucharest , 24-25 September, 2015

[101] Butean A., Bălan O., Moldoveanu A., Moldoveanu F., *Touchscreen Based Audio and Vibro-Tactile Applications as Assistive Systems for People Suffering from Eye Disorders*, The 22nd International Congress on Sound and Vibration, Florence, Italy, 12-16 July, 2015

# 11 Annexes

## 11.1 A1: Implementation examples for the touchscreen application

Android Manifest

An important step in implementing the right application manifest file is to correctly apply changes to the Manifest depending on what is needed. This file is required to be present in the application root and must have the name `AndroidManifest.xml`. This file is automatically generated when opening a new project and contains essential information about the application, being largely automatically generated by the development environment.

Set permissions is extremely important for managing the resources of the device. In order to use GPS, to be allowed to make emergency calls or use other services that require special permissions, they must be declared here. A good example in the case of this application is the permission to use the vibration motor. This helps the application to provide important feedback to the blind person. This is achieved with the following code line:

```
<uses-permission android:name="android.permission.VIBRATE" />
```

Setting the Icon

Setting the icon that will appear after installing the device you want. This change is made via the following line:

```
android:icon="@drawable/ic_launcher"
```

`Drawable` is the resource folder where we can save pictures or other assets that we need during development. `ic_launcher` is the name of the configuration icon. In this resource folder it is recommended to have more pictures of the icon, which have the same name but different resolutions. This way the application will be able to adapt to the system on which it is installed and use the icon with the right resolution.

Setting the main activity

Setting the main activity, when the application starts. By default, the application is set to begin with the first activity created when opening a new project. This can be confusing later, if we wish to change the start activity. I decided to implement an activity to allow the user to change the language for the entire text that the application will offer as feedback. This activity must be present when opening the application so that the user can choose the desired language before any feedback is offered. These changes were achieved through the following code:

```
<activity
    android:name=".Language"
    android:label="Language" >
    <intent-filter>
        <action android:name="android.intent.action.MAIN" />
        <category android:name="android.intent.category.LAUNCHER" />
    </intent-filter>
</activity>
```

Parent activity

Setting the parent of an activity from a hierarchical point of view. The parent is actually another activity that will become active when closing the child activity. For example, if the back button is pressed, the application will go to the parent activity, closing the current activity. An example of this can be seen in the code below:

```
<activity
    android:name=".Unknown"
    android:label="Unknown"
    android:parentActivityName=".Language" >
    <meta-data
        android:name="android.support.PARENT_ACTIVITY"
        android:value="com.example.bogdan.orientare.Language" />
</activity>
```

In this case, the `Unknown` activity will close when the implemented back gesture is handled and the application will go to the parent activity, `Language`.

Gesture overwriting

An example of such a gesture that was overwritten is the `onScroll` gesture, part of the first learning activity that teaches simple screen touch gestures. The preimplemented scroll gesture was altered so that the device will notify the user via the synthesizer if the gesture performed was not correct. In order not to repeat the message on every movement of the finger within the scroll gesture, a simple check was made, as can be seen in the code snippet below:

```
@Override
public boolean onScroll(MotionEvent e1, MotionEvent e2, float distanceX,
                        float distanceY) {
    Log.d(DEBUG_TAG, "onScroll: " + e1.toString()+e2.toString());
    if(ok==1)
    {
        if(lang==1)
            speakWords("This is not a single tap");
        else
            speakWords("Acesta nu este gestul corect");
        ok=0;
    }
    return false;
}
```

The ok variable is reset and becomes one when touching the screen, but after the first movement of the finger to perform a scroll, it becomes 0, in order not to repeat the message.

Vibration

In order to use vibration, the application first needs to obtain permission to use the device's vibration motor. This is done by adding the following line in the AndroidManifest.xml file:

```
<uses-permission android:name="android.permission.VIBRATE" />
```

Also, to be able to declare objects of type Vibrator, a special library must be referenced:

```
import android.os.Vibrator;
```

This way objects of type Vibrator can be declared and used for different kinds of vibrations.

Long pressing on a button

To enter the desired activity after listening to the message of the button, the user needs to press and hold that button. The following snippet shows how this is achieved.

```
button_rectangle.setOnLongClickListener(new View.OnLongClickListener() {
    @Override
    public boolean onLongClick(View v) {
        if(lang==1)
            speakWords("You entered rectangle settings. Press to read help.");
        else
            speakWords("Vă aflați în setările dreptunghiului. Atingeți ecranul
        ctexit=0;
        Intent intent = new Intent(MainActivity.this, Settings.class);
        startActivity(intent);
        return true;
    }
});
```

It handles a long `click` button event. When this gesture is performed the synthesizer will playback the message corresponding to the newly selected activity.

The `ctexit` variable is reset to 0 when any button is long clicked, except for the exit button.

Piano keys

After drawing the buttons for the piano tool, a click event handler was implemented to play the corresponding note and generate a specific vibration. Part of the code used to achieve this is illustrated below:

```
for(i = 0; i < 17; i++)
{
    final int position = i;
    noteGama1[i].setOnTouchListener(new View.OnTouchListener() {
        @Override
        public boolean onTouch(View v,MotionEvent event) {
            if (mDetector.onTouchEvent(event)) {
                if(event.getAction()==MotionEvent.ACTION_UP)
                    {
                        for(int k=0;k<12;k++)
                            ok[k]=1;
                    }
            if (event.getAction() == MotionEvent.ACTION_DOWN ||
                    event.getAction() == MotionEvent.ACTION_MOVE)
                {
```

In order to listen for all the buttons on the screen, a "for" statement has been used to go through all the elements. Touch and motion gestures are treated separately from the motion of lifting the finger from the screen. When lifting the hand from the screen the `ok[]` vector is reset, each element being assigned the value `1`. This vector represents which piano key is currently pressed. It is required in order to play sounds only when a key is first touched and not on subsequent movements of the finger over the same key. The code that checks if a certain key was pressed is the following:

```
if((event.getRawX()<relac.getRight()&&event.getRawY()>noteGama1[7].getBottom()
        &&ok[0]==1)||(event.getRawX()<noteGama1[7].getLeft()&&ok[0]==1))
{
    playSound(R.raw.ff_c1);
    vibe.vibrate(50);
    for(int k=0;k<12;k++)
        ok[k]=1;
    ok[0]=0;
    Log.v(DEBUG_TAG, " Nota   alb 0");
}
```

The check determines whether the coordinates are inside a specific key and whether it is the first touch of the button or a movement over its surface. In case the check holds and the corresponding entry in the `ok` vector is `1`, a sound will be played, the device will vibrate and the `ok` vector will be reset. The button vibrations differ by 50 milliseconds for adjacent keys so that visually impaired people can differentiate between keys even in a noisy environment.

Playing sounds is done using the `MediaPlayer` library:

```
import android.media.MediaPlayer;
```

The method `playSound(sound)` is used as illustrated below:

```
private void playSound(Integer sound){
    mp = MediaPlayer.create(Piano.this, sound);
     mp.start();
    mp.setOnCompletionListener(new MediaPlayer.OnCompletionListener() {
        @Override
        public void onCompletion(MediaPlayer mp) {
            mp.release();
        }
    });
}
```

This method receives the sound to be played as a parameter, and creates a `MediaPlayer object`. The start method must be called in order to play the sound. When the sound is finished playing, the `MediaPlayer` resources are released.

## 11.2 A2: Implementation examples for the gamepad training application

<u>Game Class</u>

`Game Class` developed using `XNA` Framework and provides initialization for basic graphics device, game logic and rendering code. By using this class, there is the possibility of writing code that can manipulate the gamepad's vibration. Within this class, there is an object called `GamePad`, that contains a method used for the programming of the vibration. This method is called `SetVibration(PlayerIndex playerIndex, float leftMotor, float rightMotor).` The parameters of this method are the following:

- `PlayerIndex`: Player index that identifies the controller to set.
- `leftMotor:` The speed of the left motor, with values between 0.0 and 1.0. This is a low-frequency motor.
- `rightMotor`: The speed of the right motor, with values between 0.0 and 1.0. This is a high-frequency motor.

The return value of this method is `true`, when the motors were successfully set, and `false` when the gamepad was not able to process the request.

The most important method within the `Game` Class is the `Update()` method. It gets as an input parameter a `GameTime object`, which represents the time passed since the last call of this method. `Update()` is called in a continuous loop, 60 times per second and within it, the gamepad controller inputs are processed and the controller can be set to vibrate continuously.

```
protected override void Update(GameTime gameTime)
{
GetInput();
      currentState = GamePad.GetState(PlayerIndex.One);
      if (f1.tabControl1.SelectedTab == f1.tabControl1.TabPages[0])
     {
           SetVibration(vibrationAmount1, vibrationAmount2);
           SetColors();
      }
     if (f1.tabControl1.SelectedTab == f1.tabControl1.TabPages[1])
     {
if (f1.Cursor == System.Windows.Forms.Cursors.NoMove2D &&
(f1.processVideo == true || f1.processImage == true))
                VibratePixel();
           else
                GamePad.SetVibration(PlayerIndex.One, 0.0f, 0.0f);
      }
if (f1.processVideo==true && f1.processImage==false &&
timePassed2.TotalSeconds >= 0.1f)
      {
      ProcessImage(f1.pictureBox1.Image); lastTime2 = DateTime.Now;
     }
      if (f1.processImage == true && f1.Clicked2 == true)
     {
           ProcessImage(f1.pictureBox1.Image);
           f1.Clicked2 = false;
     }
     timePassed2 = DateTime.Now - lastTime2;
     if (f1.Clicked == true) VibrateCbholor();
}
```

The `Update()` method is used in order to accomplish the following:

- Extract information about the scrollbars' positions and displaying the information in textboxes.
- Setting the gamepad controller vibration according to the selected intensities.
- Setting the gamepad controller vibration according to the cursor's position on the processed image or video.
- Process the image, or a frame within a video

currentState is a GamePad type of object, a class that allows the extraction of information regarding the interaction between the user and the Xbox Controller. It is also used in order to set the vibration of the two motors. GetState() method, that gets PlayerIndex. The input parameter represents the player index for the controller you want to query.

Processing a single image in the Update() method, is called in a continuous loop 60 times per second, will have a bad impact on the application, making it run slowly. A solution that I found for this problem is to take into consideration the time passed between two consecutive processes and set the condition for this time to be greater than 0.1s. In this case, a single image processing within a video will be finished faster and the problem is avoided with the processing flow kept at 10 frames/second.

It is important to mention the fact the gamepad controller will vibrate when pressing the Right Trigger and the Left Trigger of the controller, according to the value that is set in the textbox(found in LearnColors Tab). The SetVibration() function is called when the supervisor works in the first tab. This function gets as input parameters vibrationAmount1 and vibrationAmount2, which represent the intensities associated with each trigger (left an right).

This function is always called in the Update() method of Game Class, when the user is in the LearnColors tab. If one of the triggers is pressed [I.e.: if (currentState.Triggers.Left > 0.0f)], the controller will vibrate with the intensity associated with that trigger

The image processing function, ProcessImage(), gets as an input parameter an Image object. This function has the role of getting each pixel and testing the similarity between the original pixel and one of the six of the set.

```
public void ProcessImage(System.Drawing.Image image)
{
b = (Bitmap)image;
      c = (Bitmap)image;
      for (i = 1; i < b.Width; i++)
            for (j = 1; j < b.Height; j++)
           {
                  System.Drawing.Color color = b.GetPixel(i, j);
                  color=ProcessPixel(color);
                 c.SetPixel(i, j, color);
            }
      f1.pictureBox2.Image = (System.Drawing.Image)c;
}
```

This function crosses the image in order to extract every pixel. Each pixel is then processed, using the ProcessPixel() function and then updated back into the output image. After all the pixels were processed, the image will be then presented in a pictureBox alongside with the original imagine or video.

A function of great significance is the pixel processing function, `ProcessPixel()`, that gets as an input parameter a color. In `byte` type variables are saved the red, green and blue components of the original color. The values of these components are tested in order to check the closeness to one the six colors from the set.

```
public System.Drawing.Color ProcessPixel(System.Drawing.Color
pixelColor)
{
byte R, G, B;
           int WhiteLimit, BlackLimit, YellowLimit;
       R = pixelColor.R;
       G = pixelColor.G;
       B = pixelColor.B;
     if (f1.processImage == true)
           {
           WhiteLimit = Convert.ToInt32(f1.textBox4.Text);
                BlackLimit = Convert.ToInt32(f1.textBox5.Text);
                YellowLimit = Convert.ToInt32(f1.textBox3.Text);
       }
       else

           {
           WhiteLimit = 150;
                BlackLimit = 100;
                YellowLimit = 200;
     }
           if (R > G && R > B)
     {
           if (R > WhiteLimit && G > WhiteLimit && B > WhiteLimit)
                     pixelColor = System.Drawing.Color.White;
                else
                     if (R < BlackLimit && G < BlackLimit && B <
BlackLimit)
                          pixelColor = System.Drawing.Color.Black;
                     else
                     {
                          if (R>YellowLimit && G > B)
                               pixelColor =
System.Drawing.Color.Yellow;
                          else
                               pixelColor = System.Drawing.Color.Red;
                     }
     }
```

```
      else if (G > R && G > B)
      {
            if (R > WhiteLimit && G > WhiteLimit && B > WhiteLimit)
                  pixelColor = System.Drawing.Color.White;
                  else
                      if (R < BlackLimit && G < BlackLimit && B <
BlackLimit)
                              pixelColor = System.Drawing.Color.Black;
                      else
                              pixelColor = System.Drawing.Color.Green;
            }
      else if (B > R && B > G)
      {
            if (R > WhiteLimit && G > WhiteLimit && B > WhiteLimit)
                  pixelColor = System.Drawing.Color.White;
                  else
                      if (R < BlackLimit && G < BlackLimit && B <
BlackLimit)
                              pixelColor = System.Drawing.Color.Black;
                      else
                              pixelColor = System.Drawing.Color.Blue;
            }
      else if ( G==R && R>B)
      {
                  if (R > WhiteLimit && G > WhiteLimit && B >
WhiteLimit)
                  pixelColor = System.Drawing.Color.White;
                  else
                      if (R < BlackLimit && G < BlackLimit && B <
BlackLimit)
                        pixelColor = System.Drawing.Color.Black;
                      else
                              pixelColor = System.Drawing.Color.Yellow;
      }
      return pixelColor; }
```

The main idea in creating this function is the usage of a series of tests on the components of the input color. For example, in order to test if a certain pixel is closer to blue color, the next steps need to be followed:

1. Initially, the blue component of the color is tested, verifying if its value is larger than the values of the other two components.

2. The next step is to check if the value of each component is greater than a certain threshold, named suggestively `WhiteLimit`. This is done in order to test if the input pixel is closer to the white color.
3. The last step is to check if the value of each component is smaller than a certain threshold, named suggestively `BlackLimit`. This is done in order to test if the input pixel is closer to the black color.

It is worth mentioning the fact that those thresholds can be modified by using the `scrollBar` which is located in the `PerceiveColors tab`. These modifications can only be made if an image was loaded. For the video, the thresholds stay the same.

The `VibratePixel()` function is used in order to set the controller's vibration when the mouse cursor is moved along the processed image or video. The idea of this function is to get the coordinates of the cursor inside the image and to test the color of the pixel that is located at those coordinates.

```
public void VibratePixel()
{
pixelx = f1.cpX - 783;
      pixely = f1.cpY - 232;
      Bitmap image = (Bitmap)f1.pictureBox2.Image;
      System.Drawing.Color color = image.GetPixel(pixelx, pixely);
      if (color.Name == "ffffffff")
        GamePad.SetVibration(PlayerIndex.One, 1 / 6.0f, 1 / 6.0f);
      else if (color.Name == "ffff0000")
       GamePad.SetVibration(PlayerIndex.One,(1/6.0f)*2,(1/6.0f)*2);
      else if (color.Name == "ffffff00")
       GamePad.SetVibration(PlayerIndex.One,(1/6.0f)*3,(1/6.0f)*3);
     else if (color.Name == "ff008000")
       GamePad.SetVibration(PlayerIndex.One,(1/6.0f)*4,(1/6.0f)*4);
      else if (color.Name == "ff0000ff")
       GamePad.SetVibration(PlayerIndex.One,(1/6.0f)*5,(1/6.0f)*5);
     else if (color.Name == "ff000000")
       GamePad.SetVibration(PlayerIndex.One, 1.0f, 1.0f);
}
```

Two variables, `pixelx` and `pixely`, are used in order to save the coordinates of the cursor. From these values, it is mandatory to subtract 783, respectively 232, which represent the fixed coordinates of the upper-left corner of the pictureBox `control` that contains inside the processed image or video.

Afterwards, in a `Color` type variable, the pixel located at coordinates `pixelx` and `pixely` is saved. Using the `ProcessPixel function`, the name of the color located at those coordinates is verified and in the end, the controller is set to vibrate with the intensity associated with that color.

Form1 Class

This class is used so that the application offers a graphical user interface that allows a way to set different intensities, to visualize the associations between the intensities and the six colors and to display the video from the webcam or to display an image loaded from the computer.

The color panels that can be pressed are numbered within the Form from 25 to 30 and the `OnClick` event on one of the panels was handled in the following way:

a. In a variable, named `aux`, the `sender` of the event was saved, which represent the name of the panel that was pressed
b. If `aux` is different than `NULL`, in a `string` variable, the name of the Panel is saved
c. Using `Substring(5)` on the name of the Panel, followed by an `Int32` conversion, the number of the Panel that was pressed is deducted.
d. `vibrationAmount` is calculated as `(nr_panel-1) % 6 + 1`; for example, for Panel25 (painted WHITE), the calculus would be: `(25-1) % 6 + 1 = 1`, which represents the intensity associated with the White color.

The code used for handling the event:

```
void vibrate(object sender, EventArgs e)
{
      aux = sender as Panel;
     if (aux != null)
     {
            string name = aux.Name;
            string nr_string = name.Substring(5);
            float nr = Convert.ToInt32(nr_string) / 1.0f;
            vibrationAmount = (nr - 1) % 6 + 1;
            Clicked = true;
            Vibrate = true;
            aux.BorderStyle = BorderStyle.Fixed3D;
            for (j = 0; j < 6; j++)
                  p2[j].Enabled = false;
}
}
```

Additionally, an important event that needs to be handled is the `MouseMove` event for the cursor on the processed image or video frame.

```
private void pictureBox2_MouseMove(object sender, MouseEventArgs e)
{
      Cursor = new Cursor(Cursor.Current.Handle);
      this.Cursor = System.Windows.Forms.Cursors.NoMove2D;
      cpX = Cursor.Position.X;
      cpY = Cursor.Position.Y;
```

```
}
```

For this event, it is important to get, in a `Cursor` variable, the cursor found in the current handle, so we could find its X and Y coordinates. These coordinates are used in order to test the color of the pixel found at those coordinates, in the `VibratePixel()` function, previously explained.

<u>WebCam Class</u>

In order to be able to use this class [86], a DLL file needs to be downloaded and included as a reference in the project, along with the `WebCam class`. This class contains a variable, named `WebCamCapture`, which will be used in the methods associated with the `Webcam class`. These methods, used in the development of the application, provide a way to control the webcam and they are presented below:

WebCam object initialization:

```
public void InitializeWebCam(ref System.Windows.Forms.PictureBox
ImageControl)
{
      webcam = new WebCamCapture();
     webcam.FrameNumber = ((ulong)(0ul));
      webcam.TimeToCapture_milliseconds = FrameNumber;
webcam.ImageCaptured += new
WebCamCapture.WebCamEventHandler(webcam_ImageCaptured);
       _FrameImage = ImageControl;
}
```

This method gets as an input parameter a `PictureBox` object, which represents the `pictureBox` that is used to display the video. The frame number is initialized with an unsigned long 0. The `TimeToCaputre_miliseconds` member of the `WebCamCapture` structure is initialized with the number of frames that need to be displayed per second. Moreover, the event handle for the image capture is added along with the `_FrameImage` initialization with the input parameter, the `ImageControl` object.