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# Assistive devices for visually impaired people

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Παράβαση της ανωτέρω ακαδημαϊκής μου ευθύνης αποτελεί ουσιώδη λόγο για την ανάκληση του πτυχίου μου».

Ημερομηνία
10/07/2021

Ο Δηλών

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# Glossary

**VIP**: Visually impaired people

**US**: Ultrasound sensor

**ATs**: Assistive technologies

**p-EVES**: portable electronic vision enhancement systems

**IoT**: Internet of Things

**AI**: Artificial intelligences (AI)

**RFID**: Radio Frequency Identification

**ETAs**: Electronic travel aids

**EOAs**: Electronic orientation aids

**PLD**s: Position locator devices

**IR**: Infrared

**SRAM**: Static random access memory

**PCB**: Printed Circuit Board

# Abstract

This thesis marks an attempt to better fathom the magnitude of visual impairment as a health issue, the needs of affected individuals, the available assistive technologies and also tries to provide an insight into the development of two affordable and reliable assistive systems for visually impaired people.

Despite the enormous efforts in designing reliable and user-friendly assistive devices for the visually impaired people there is plenty of room for improvement as usually these devices are bulky, complex in operation, expensive and in some cases fail to attain the initial claims by manufactures and researchers, leading to disappointment and frustration among the visually impaired people.

In an effort to address these issues and to provide a helping hand to this vulnerable part of society, we developed two assistive devices. The first is a mobility aid device that is wearable in form of a wrist or hand mounded glove embedded with two ultrasonic sensors that aim at identifying potential obstacles. When obstacles are identified the user is notified by beeping sounds of high or low intensity. The high intensity sound is activated when the identified obstacles are positioned at head level whereas the low intensity sound is triggered for obstacles that are positioned from ground to chest level. The second device is a home assistance system that enables visually impaired people to remotely control through voice commands lights, cooling system or any other household appliance. In addition, this systems is able to notify the user through voice messages about the detection of fire, the overcoming of specific limit in temperature and in which room has entered.

The gathered result from the testing of the systems indicate that the majority of the initially set goals are successfully accomplished. Testing of mobility aid system confirmed the fact that is intuitive in use, less obstructive, lightweight and user-friendly. As a shortcoming was identified the difficulty in detection of small objects and those that are at ground level. Regarding the testing of home assistance system, it was observed that its performance satisfies all the initially set objectives as the utilized sensors have a fast response, voice messages are generated correctly and under low noise environment the control of home appliances is attained easily.

Lastly, we acknowledge the fact that the proposed systems are far from the optimal solution for the visually impaired people and thus future enchantments are planned to be implemented. However, we believe that they have the potential to make a beneficial contribution in the lives of visually impaired people as their designs were based on a thorough examination of the strengths and weaknesses of past works and understanding of visually impaired people’s needs.

**Keywords:** visual impairment, assistive technologies, mobility aid, home assistance, obstacle detection, ultrasounds, voice commands, remote control.

# Acknowledgements

Completing this thesis has been a challenging and exciting experience. I would not have been able to accomplish this goal without the help of many people and therefore in this section I take the chance to express my gratitude for their help.

Frist and foremost, I would like to express my deep sense of gratitude to my supervisor, professor Pantelis Asvestas for his guidance, suggestions, patience, invaluable feedback and fruitful collaboration.

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# CHAPTER 1: Introduction

## 1.1. Problem statement

Vision is considered to be the most crucial human sense as 83% of information from the environment is obtained via sight [1]. Sight enables people to successfully function in their daily life by providing them with the ability to navigate efficiently their surrounding environment, participate in social interactions, perform actions, access information and recognize danger.

Consequently, lack of vision has a devastating impact on the quality of life and psychological status of affected individuals. Visually impaired people (VIP), face tremendous barriers in their routine life such as lack of independence and confidence as they are deprived from performing many of the daily tasks and usually relay on others for their mobility. In many cases, unaccompanied VIP are prone to accidences and injuries as they often are unaware of the dangers that lay ahead and run in high risk of colliding with obstacles [2-4].

In addition, the dimension of this issue become more concerning as it presents a serious financial challenge on families and governments. For instance, in the US, statics indicate that unemployment rate among blind people is extremely high as around 75% of working-age blind struggle to find employment while a huge portion of visually impaired children are analphabet as only 10% of school-age blind receive the appropriate education and learn how to read in Braille. In effort to assist the blind to deal with their daily task and live a productive life authorities and their loved ones make huge expenses to offer them the appropriate health care and specialists. A wide variety of qualified personnel which usually is insufficient to cover the actual demands is involved in helping the blind such as Braille teachers, psychologists, orientation and mobility specialists, vision rehabilitation therapists etc. [5].

According to statistics provided by the World Health Organization (WHO), there are approximately 1.3 billion people living with some form of vision impairment, out of which 36 million are totally blind, 188.5 million people have mild vision impairment and 217 million have moderate to severe vision impairment. Approximately 80% of all vision impairment globally is considered avoidable and majority of people with vision impairment are over the age of 50 years. About 87% of the blind people live in low-income countries or developing countries and by the 2050 the percentage of visually impaired people is expected to triple due to the rapid increase of population, longer life expectancy and increased survival of premature infants [6, 7]. The figure below (Figure 1) shows the percent of blind people across the globe.

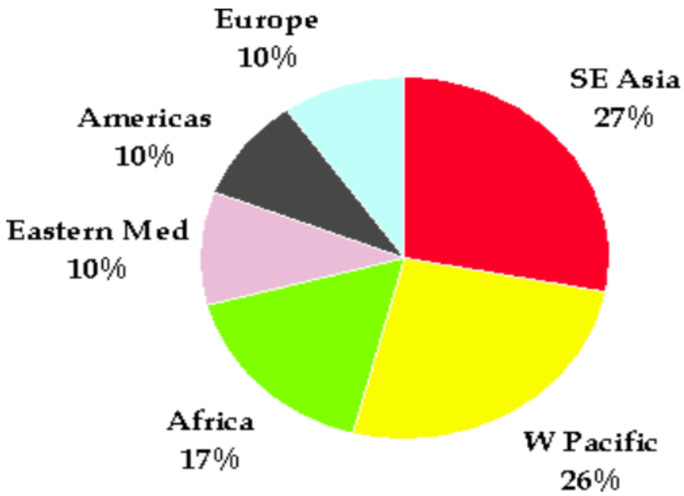



*Figure 1: A pie chart showing blind people across the world.*

Moreover, in order to support the blind in their daily life along with the medical treatment, traditionally white cane and trained dogs are used to provide a helping hand. Despite the help that these methods provide as we will see in more detail in the next chapter their use is associated with several imperfection and drawbacks such as lack of effectiveness in identifying the potential barriers making the mobility of blind difficult, restricted and even dangerous [2, 8].

Therefore, more sophisticated means are urgently required to assist this vulnerable part of society. Thanks to human ingenuity and recent technological advancement in the field of electronics and engineering several assistive device are developed to provide independence and comfort in locomotion and daily life of VIP. Most of those devices focus on areas such as information access, smart cities and mobility aid.

Despite the fact that these assistive tools seem quite intelligent and promising as we will examine in the next chapter they seem be quite costly, bulky, complex and often do not meet the initial claims by manufactures and researchers, leading to disappointment and frustration among the visually impaired people [9].

## 1.2. Motivation and proposed system

By taking in consideration the following facts such as the increasing number of blind people worldwide, the age and financial condition of the majority of VIP and the noticeable differences between users and designers perspective we purpose two devices to assist visually impaired people:

**i.** The first device is a mobility aid system that may not look fancy as a design but is affordable and addresses efficiently the main needs of visually impaired people. The device is designed in a form of a wrist or hand mounded glove embedded with two ultrasonic sensors (US) to measure the distance of nearby obstacles. The US sensors are connected to an Arduino Nano device that can process the received data and estimate the distance of obstacles. When obstacles are detected within the predefined distance the user is alerted through a beeping sound of low intensity or high intensity. The high intensity sound is generated when the detected obstacles are at head level whereas the low intensity sound is activated for obstacles that are from ground to chest level.

**ii.** The second device is a smart home assistance system that aims at assisting the blind with their daily home activities. This device has two main features:
- The first is that can help VIP to control lights, cooling system and any other home appliance using voice commands.
- The second is that can notify VIP via voice messages when they change room within the home, when the temperature passes a specific limit and when fire is detected.

## 1.3. Objectives

### i. Mobility aid system

- Wrist or hand mounded glove, flexible and light weight design.
- Cost-effective and intuitive in use.
- Real-time device: it should work as fast as the average reaction time of human.
- Provide confidence to visually impaired people to navigate independently in outdoor and indoor environments.
- Use ultrasonic sensors to detect floor and hanging obstacles with a sensing area of 1.5m.
- Inform the user about obstacles through beeping sound of low and high intensity.

### ii. Home assistance system

- Remote control of household appliances with voice commands.
- Voice notifications in case of high temperatures, fire detection and change of room.

## 1.4. Thesis overview

Each chapter is arranged as follows:

- Chapter 1: Introduction
  In this chapter is discussed the magnitude of the visual impairment as a health issue, our motivation, the proposed systems and theirs objectives.
- Chapter 2: Background and related work
  Here are explained some basics concepts related to visual system, types of visual impairment, brain plasticity, echolocation and then is provided a presentation of main categories of assistive technologies for the VIP.
- Chapter 3: Hardware and software analyses
  This chapter includes an analysis of the overall architecture of the proposed systems and also it contains details regarding the hardware and software components.
- Chapter 4: Implementation and evaluation
  This sections presents the testing and training of hardware components, the assembly process and final form of proposed systems and also the methodology utilized to evaluate their functionality.

- Chapter 5: Conclusion and future work
  In the final chapter conclusion are drawn about the functionality of our devices and also future improvements are suggested.

# Chapter 2: Background and related work

## 2.1. Anatomy and function of visual system

The way that we perceive our surrounding environment depends on the function of the visual system. The function of human visual system can be considered analogous to that of two cameras connected to a computer through wires. In this analogy the cameras are the eyes, the computer is the brain and the wires are the optical nerves [10].

i. **The eye:** Human eye (Figure 2) has an approximately spherical shape and is embedded in a protective framework of bones and connective tissues called the orbit. The eye can be divided in the following structures[11, 12, 13]:

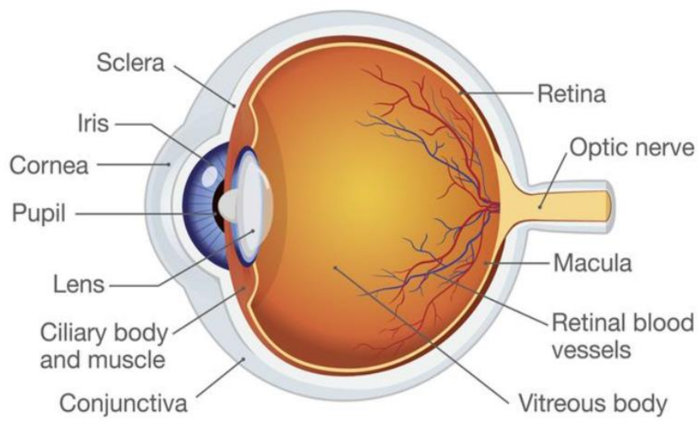



*Figure 2: Main structures of human eye.*

a) **Three coating layers**

- **Fibrous tunic** is the thickest and hardest part of the eyeball and contains the cornea and the sclera. Cornea forms the front of the eyeball, it is known as the "window" of the eye as it is a transparent surface through which the light enters and it has a significant impact on the eye's focusing power. Sclera is hard, white layer that surrounds the cornea and provides bloods vessels and neurons inside the eye with protection.
- **Vascular tunic** is the middle layer that surrounds the eye and is composed by the iris, ciliary body and the choroid. The iris is placed on the top of the lens, it controls the size of the pupil and similarly to the aperture of a camera it is able to control the amount of light entering the eye. Moreover, it determines the color of the eye with the amount of pigments that contains. The ciliary body is responsible for controlling the optical power of the lens through ciliary muscle that adjust the shape of the lens for far or near sight. Choroid contains melanin a dark pigment that limits the uncontrolled reflection within the eye and it is composed of blood vessels that provide the eye with necessary oxygen and nutrition.
- **Retina** is part of central nervous system and it is composed of five different layer of neurons: the visual receptor cells, the horizontal cells, the bipolar cells, the amacrine

cells, and the retinal ganglion cells. From which only receptor cells, bipolar cells and ganglion cells consist direct pathways for the transmission of visual information from eyes to the brain. The visual receptor cells create a light-sensitive layer of tissue at the back of the eye that similarly to the film in the camera captures the light rays and through the photosensitive cells called rods and cones converts them into electrical signals. Rods which are triggered by the low levels of light provide the perception of black and white vision while cones are activated in higher levels of light and assist in distinguishing the colors. Due to the synapses that exists between different types of neurons signals are passed from the receptor cells to bipolar cells and to ganglion cell whose sensory fibers create the optic nerve which carries the neural responses to the visual cortex of the brain. The region of the retina where the optic nerve exits the retina is known as the blind spots as vision is impossible due to the lack of photoreceptors [14].

**b) Inner part**

- **Lens** is a transparent elliptic structure that has no blood vessels. Light is refracted by the lens and with the help of the cornea images of the external world are focused on the light sensitive retina. The image formed by the eye's lens is much smaller than object viewed because light rays are bent when they are brought into focus. Furthermore, the image on the retina is inverted (upside-down) and reversed (right-left). Contraction and relaxation of ciliary muscle changes the size and the shape of the lens affecting in this way the refractive properties of the eye and thus enabling the vision of distant and near objects.
- **Vitreous body** is a clear gelatinous structure that occupies the majority of the eyeball and its main role is to maintain the structural integrity of the eye.
- **Anterior and posterior chambers** which are filled with aqueous fluid are located between the iris and the cornea and between the iris and the lens respectively and have as the goal to provide cornea and lens with nourishment.

**ii. Visual cortex**

After exiting the retina optic nerves from both the eyes meet and cross at the optic chiasma (Figure 3) which is positioned at the base of the hypothalamus of the brain. Because of the optic chiasma visual information from the right portions of the visual field are send to the left optic tract and visual information from the left portions of the visual field are send to the right optic tract. These data are then combined to allow us to see the entire visual field. The optic tracts sweep around the hypothalamus and the visual information goes through the lateral geniculate nucleus (LGN) of the thalamus to the visual cortex where are processed. Based on the structural and functional classification the visual cortex is divided into five different areas (V1 to V5), each subsequent area is more specialized than the last. Initially, the visual information reaches the primary visual cortex (V1) and then is transcended to deeper layers for higher level processing. The processed information from the visual cortex is subsequently sent to other regions of the brain to be analyzed and utilized. This process is highly specialized and allows the brain to quickly recognize objects and patterns without a significant conscious effort. Characterizing how all of these processes function and integrate together remains an active field of research [14, 15].

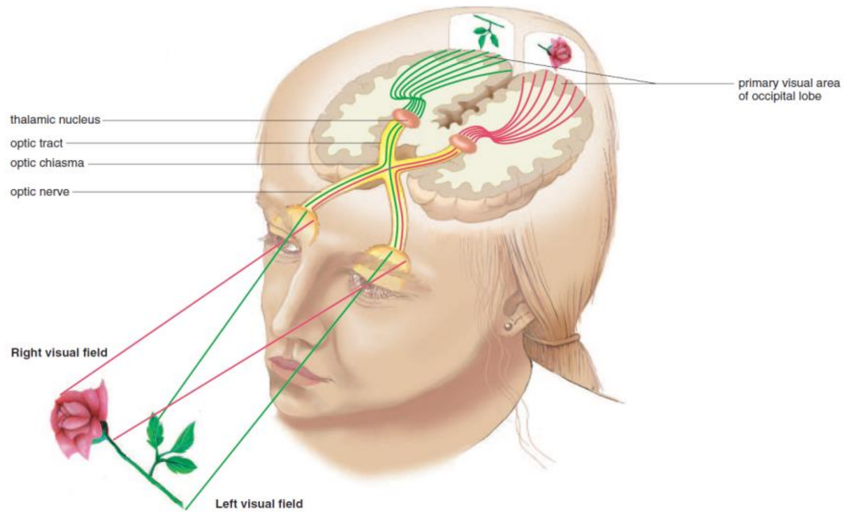



*Figure 3: Visual pathways from the retina to the visual cortex.*

## 2.2. Visual acuity and types of visual impairment

Visual acuity is a classical sight parameter that indicates the sharpness or the clarity of vision, measured by the ability to discern objects at a given distance according to a fixed standard. Typically, measurement of visual acuity is performed using specialized charts. The most common of charts are the Snellen and Bailey-Lovie or ETDRS charts [16].

Usually, a Snellen chart is comprised of eleven lines of block letters (Figure 4.a). The first line consists of one very large letter, in the subsequent lines the number of letters increases whereas their size decreases. In order to have the maximum contrast letters are represented as black symbols with white background. During the test the patient covers one eye, sits at viewing distance of 6m or 20 feet and tries to identify the letters on the chart that are formally known as optotypes. At this distance letters subtend an angle of 5 minutes (min) of arc and each letter part subtends an angle 1 min of arc. Vision acuity is expressed in terms of Snellen fraction with the 6/6 or the 20/20 in the US to be considered normal. In the expression 6/x vision, the numerator (6) is the distance in meters between the subject and the chart and the denominator (x) the distance at which a person with 6/6 acuity (normal' eyesight) would discern the same optotype. Thus, 6/12 means that a person need to approach to a distance of 6 meters (20ft) to read letters that a person with normal acuity could read at 12 meters (39 ft) [17, 18].

Alternatively, visual acuity can be tested using Bailey–Lovie charts (Figure 4.b) that overcome the most noticeable drawback of Snellen charts that is the variable size and number of letters among lines. The chart was initially developed by Drs Ian Bailey and Jan Lovie in 1976 and was later modified for use in the Early Treatment Diabetic Retinopathy Study (ETDRS). In this chart the number of letters on each line is the same and their size diminishes logarithmically form line to line. Visual acuity is scored with reference to the Logarithm of the Minimum Angle of Resolution and the chart is also named LogMAR chart. The following equation relates LogMAR and Snellen acuity [16, 18].

$LA = \log_{10}\left(\frac{1}{S}\right)\ Eq.1$ e.g. $LA = \log_{10}\left(\frac{1}{20/40}\right) = 0.3$

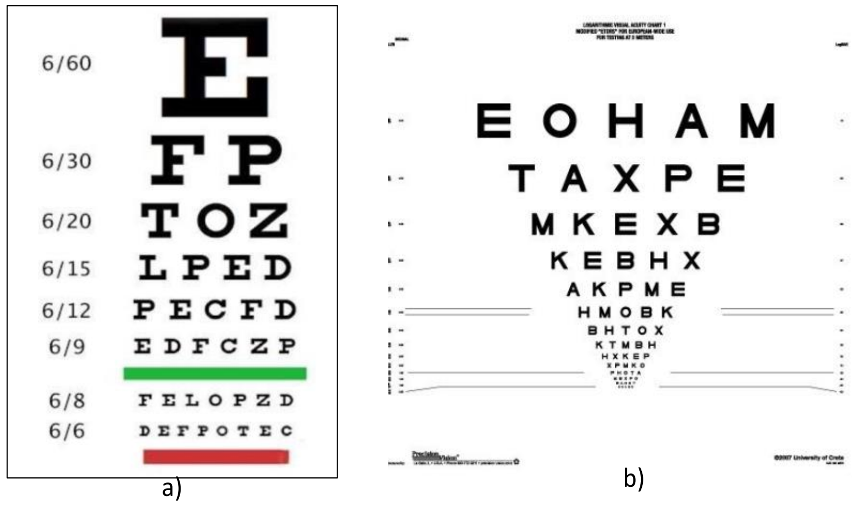



*Figure 4: Visual acuity charts: a)* Snellen chart and b) LogMAR chart.

According to the International Classification of Diseases 11 (2018), visual impairment can be classified into two groups [6]:

**a) Distance vision impairment**
- Mild – presenting visual acuity worse than 6/12.
- Moderate – presenting visual acuity worse than 6/18.
- Severe – presenting visual acuity worse than 6/60.
- Blindness – presenting visual acuity worse than 3/60.

**b) Near vision impairment:** Presenting near visual acuity worse than N6* or M.08 with existing correction.

*N6 is used to characterize the normal near vision with the 'N' referring to near and '6' referring to the size of the letters.

## 2.3. Leading causes of visual impairment

Vision impairment is attributed to several diseases, conditions, and injuries that may affect any component of the visual system. According to the WHO the main causes for the damage or dysfunction of the visual system are the following [6]:

**a) Uncorrected refractive errors** undermine the ability of the eye to clearly focus images on the retina. Usually, the result of the refractive errors is blurred vision and sometimes can lead to visual impairment. According to the WHO refractive errors manifest themselves in the following forms [8, 19]:
- **Myopia (nearsightedness):** difficulty in seeing distant objects clearly.
- **Hyperopia (farsightedness):** difficulty in seeing close objects clearly.
- **Astigmatism:** distorted vision resulting from an irregularly curved cornea, the clear covering of the eyeball.
- **Presbyopia:** which leads to difficulty in reading or seeing at arm's length, it is linked to ageing and occurs almost universally.

The occurrence of refractive errors cannot be prevented, but an eye examination can easily diagnose them in early stages. Depending on the amount of the defect, patient's age and occupational requirements, refractive errors are treated with corrective glasses, contact lenses or refractive surgery.

**b)** **Cataract** is usually related to the ageing process and it is caused due to opacification of the lens. As a result of cataract the normal transparency of the lens is lost and the passage of the light is impeded. Similarly to the refractor errors cataract cannot be prevented, but can be addressed successfully with cataract surgery which has proven to be one of the most cost-effective healthcare intervention as it offers restoration of the vision acuity to near normal levels and substantial improvement in the quality of the life.

**c)** **Age-related macular degeneration (AMD)** is manifested in two form 'wet' and 'dry' with the dry form being the most prevalent. This condition involves the loss of the person's central field of vision and it is considered to be the leading cause of blindness in the developed countries. Research, suggest a strong link between smoking cigarettes and macular degradation as has been found that the risk in smokers can be three to five times higher compared to non-smokers. An effective treatment method does not exist as the existing treatments are limited to the wet form and can be successful only if the diagnosis is made at an early stage.

**d)** **Glaucoma** is caused by the damage of the optic nerve and is considered to be the third leading cause of blindness worldwide. The main forms of this condition are the primary open-angle glaucoma which is more prevalent in whites and Afro-Caribbeans and the primary angle-closure glaucoma which is more prevalent in South-East Asia. The risk for developing glaucoma is increased due to aging process, genetic predisposition and increased intraocular pressure. Glaucoma cannot be prevented but regular eye examination can help in early detection and avoidance of visual loss.

**e)** **Diabetic retinopathy** is a complication of the diabetes mellitus characterized by the damage of retina. The condition is divided into two stages non-proliferative diabetic retinopathy (NPDR) in which blood vessels swell and leak and proliferative diabetic retinopathy (PDR) in which the process of neovascularization starts (growth of new blood vessels). The detection of diabetic retinopathy is done by fundus photography [**19, 20**].

**f)** **Trachoma** is an infectious disease caused by bacterium Chlamydia trachomatis. The disease is more prevalent in poor countries where lack of hygiene, crowded households, water shortage and sanitation facilities offer the ideal environment for the spread of the disease. The bacteria can be transmitted from person to person directly or indirectly (flies or clothing) and repeated infection can result in permanent blindness [**20, 21**].

**g)** **Cornea opacity** is an eye disorder that results in clouding of the cornea and it affects the passing of the light through the cornea to the retina and eventually leads to a decrease in vision acuity. Chances for developing cornea opacity increase due to trauma, infection, corneal edema, and corneal dystrophies [**22**].

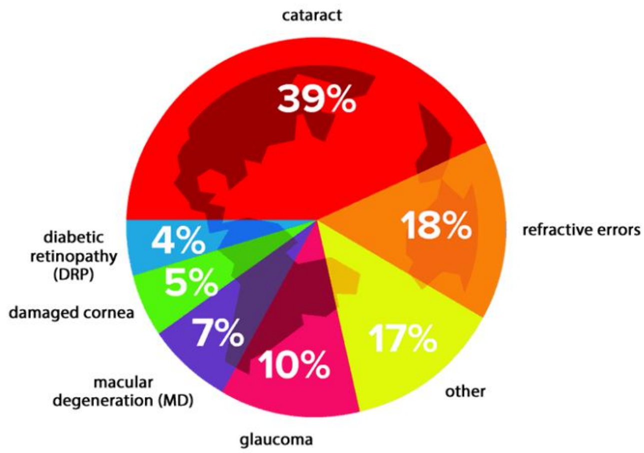



*Figure 5: Chart of Percent of types of blindness*

## 2.4. Brain plasticity and sensory compensation

Given the fact that about one third of cortical surface is involved in visual functions [23] it is important to understand the anatomical and functional changes that happened in the visual cortex due to visual loss and the effects that those changes have on the remaining senses.

Anecdotal accounts [24] suggest that blind people develop exceptional acuity in their remaining senses to compensate for their visual depravation. However, the initial research in this field [25, 26] involving animal and human studies indicated that there is a negative impact on the remaining senses due to the lack of vision. This idea is based on the fact that vision plays a significant role on the calibration of remaining sensory modalities especially those involved in spatial perception of the environment such as hearing and touch [27].

Despite the fact that the initial findings revealed that visual loss can lead to a detrimental effect on the remaining sense, recently a vast body of investigation [28-42] involving the use of neuroimaging tools that allow the in-vivo investigation of the brain and more sophisticated experimental settings were able to scientifically confirm that some of the remaining senses are heightened in blind individuals. The main findings resulting from these studies are reported below:

**i.** By employing functioning magnetic resonance imaging (fMRI) techniques scientists were able prove the enhanced speech comprehension skills of blind individuals. More specifically, studies reported that blind people are able to comprehend ultra-fast speech at a rate of up to about 22 syllables per second (syl/s) which is perceived as noise by sighted people and exceeds by far the maximum rates (6-8 syl/s) of normal-sighted listeners. During the performance of this auditory task the acquire brain images (Figure 6) indicated an activation of visuals processing regions of the brain (occipital cortices) in congenital and late bind individuals whereas in normal sighted individual the activation where limited or non-existed. The engagement of visual cortex in non-visual tasks was caused by the remarkable ability of the brain to reorganize itself due to its 'plastic' properties leading to considerably enhanced auditory senses in blind individuals compered to sighted ones. This ability can significantly assist blind people to cope with the demands of college or university education as it can enable them to study large amounts of written text using text-to-speech systems [29-33].

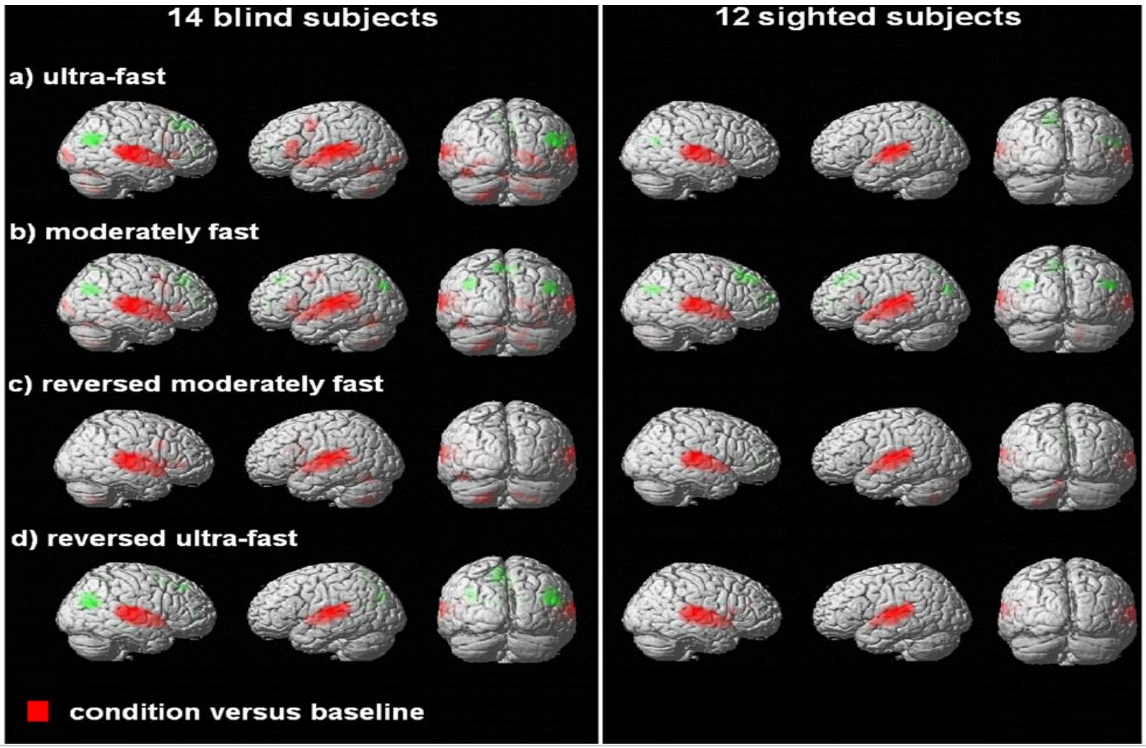



*Figure 6: fMRI brain images for bind and sighted subjects during the speech comprehension experiment.*

**ii.** Findings regarding the existence of superior tactile senses in blind individuals are not always consistent. For instance, as presented in recent reviews [23, 33] many studies have revealed that tactile perception of blind subjects resembles that of sighted control subjects in discriminating orientation, motion and shapes and suggest that any superior ability is practice-related. Characteristic is one study [34] conducted on large group of subjects with varying degrees of Braille reading experience that tested grating orientation on the index, middle and ring finger of both dominant and non-dominant hand and on the lips. Results indicated that blind participants demonstrated superior performance than the sighted on the finger, but not on the lips and proficient blind Braille readers performed better with the preferred reading finger than with the other fingers giving further support to the practice-related hypothesis. On the other hand, several other studies demonstrate heighted tactile performance in blind individuals with one study reporting that the average tactile acuity of blind subjects was similar to that of the average sighted subject 23 years younger [35]. The main reasons for these discrepancies in the literature seems to be the inter-subject variability and the technical challenges of developing an appropriate task that can enable an accurate assessment of tactile acuity [33, 35].

**iii.** Studies regarding spatial hearing of blind individuals report a trade-off in their sound localization proficiency [33, 36]. For instance, blind individuals have been shown to possess superior monaural localization abilities in the horizontal plane, but inferior localization abilities in the vertical plane, suggesting that the localization proficiency in one auditory spatial plane comes at the expense of the other. Why this trade-off occurs remains unclear, however, possible explanations may be the:

- The horizontal plane may be more relevant for navigational and way-finding tasks.
- Lack of visual calibration may be more detrimental in vertical than in horizontal sound localization.
- Localization in the vertical plane relies primarily on spectral notch cues, whereas localization in the horizontal plane appears to depend on the analysis of covert spectral features.

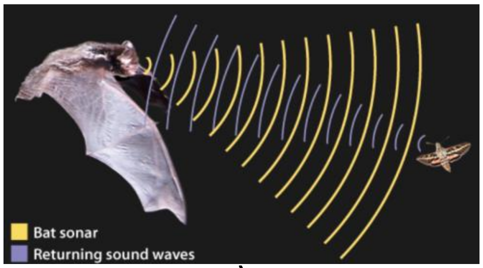
Contradictory results have also be found about the spatial hearing abilities of bind in the egocentric (use body or body parts as center of the environment) and allocentric (the center is an external object or the environment its self) frames of reference with studies suggesting that blind individuals demonstrate spatial hearing deficit when performing tasks that require the use of an allocentric frame of reference. Furthermore, investigations concerning the auditory depth perception have revealed that blind individuals perform better when making relative depth judgments and worse when making absolute distance judgments compered to sighted individuals. Usually, blind individuals utilize auditory cues as in the case of echolocation to estimate the distance that separate them form the objects [33, 37]. A more details analysis about echolocation is presented in the next section.

**iv.** Congenitally blind individuals tend to have a more advanced development of their non-visuals senses compered to late blind due to the fact that the reorganization and rewiring of the brain in more extensive in the early years of life [38, 49]. Evidences obtained with late-blind individuals suggest that the plasticity found in adulthood tends to result from different neurophysiological mechanisms. For instance, plasticity may be caused by the recruitment of existing but unused or masked pathways and not by the creation of new networks that are commonly found in early blind individuals [40].

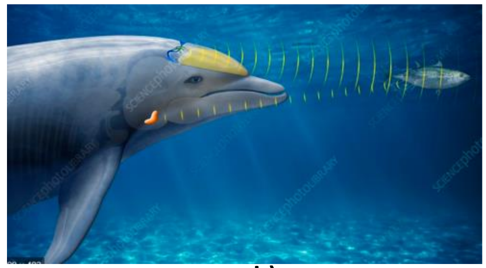
**v.** Lack of vision can act as double-edged sword [41] in blind people as on the one hand can provide them with exceptional non-visual senses but at the same time can cause a permanent changes in the visual cortex leading impossible restoration of vision in the future. The occurrence of these irreversible changes is attributed to the weakening, substitution and eventual elimination of synapses dedicated to vision due to the lack of visual input [42]. A prime example of these irreversible changes is identified in cases of reduced visuals acuity in patients who have undergone cataract removal surgery following prolonged periods of visual depravation [39].

## 2.5. Echolocation

The term echolocation or biosonar was coined in 1944 by Donald Griffin, a zoologist at Harvard who studied the outstanding ability of bats to navigate in dark and to locate pray using sound. Bats' echolocation (Figure 7.a) is inaudible to human ears as the emitted signals lie mainly in the ultrasonic range (>20Hz). Ultrasonic signals due to the high frequency have short wavelengths and therefore can be reflected from small targets such as insects providing information about their size, position and direction of movement. The ability of echolocation is present and in several other animals such as marine mammals (e.g. dolphins (Figure 7.b.), toothed whales etc.) which use echolocation to navigate, detect objects, hunt and communicate [43, 44].




a)



b)

*Figure 7: Echolocation during hunting: a) Bats and b) Dolphins.*

Similarly to animals, but in limed extend blind humans have also developed echolocation skills to navigate and sense objects in their surroundings. Initially, studies that examined echolocation in human faced difficulties to fathom the process of echolocation and referred to it as "facial vision" or "obstacle sense" because was believed that the detection of obstacles was done by pressure changes on the facial skin. Subsequent research revealed that sound and hearing were the driving aspects of this phenomenon replacing the notion of facial vision by that of echolocation. Reflected sound waves enable blind people to scan the environment and gain great deal of information regarding the position, distance, size, shape, material and texture of objects. Some skillful echolocetors have a high level of independence in their life as they are able to perform more complicated and demanding activities such as hiking, mountain biking and playing basketball. Blind humans make use of audible sound that are produced by tapping of the long cane, tongue clicking, clapping, footsteps, chips and hisses. Generally, investigations suggest that sound that are produced near the ears are the more effective for echolocation of objects with the clicks that are produced orally by rapidly moving the tongue in the palatal area behind the teeth being the most effective. Regarding the effect that the duration of the sound has on the accuracy of echolocation a recent review indicates that there is some discrepancy in studies as some suggest that the longer the duration the better the effectiveness while other support the opposite view [**43, 45-46**].

Furthermore, various experiments have revealed that sighted individuals can also learn to echolocate but their performance is noticeably worse than that of blind individuals. Bind people seem to have superior abilities because they relay extensively on echoic information and most of visual cortex is recruited for auditory processing. The onset of blindness seems also to play a crucial role in echolocation abilities of blind individuals with several studies pointing the fact that early-blind individuals possess more enhanced echolocation skills compered to late-blind. In addition to the after-mentioned benefits echolocation has also lead the foundation for the development of numerous assistive device for the blind providing more spatial awareness and safer mobility to blind individuals [**43, 47**].

In conclusion, is clear that echolocation can have a profound effect on blind individuals' life and thus, it is imperative that blind people are encouraged to practice it and the organizations that work with the blind add it in their mobility curriculum [**48**].

## 2.6. Assistive technologies (ATs) for the VIP

Over the last decades, the explosion of new and innovative technologies combined with the better understanding of human physiology and anatomy have tremendously improved the healthcare sector. Undeniably, the development of aids for the VIP that aim at enhancing the life quality and ensuring independence in daily task has been one of main focuses of these technological advances and thus, as reported in a recent study [49] ATs for blindness and visual impairment far outnumber other ATs. Research regarding the ATs [5, 8, 50-51] for VIP have mainly focused in three categories: 1) information access, 2) smart city and 3) mobility assistance. Each category can be divided in low-tech and high-tech aids, exception are the smart city systems which are predominantly high-tech. (Figure 8). As low tech aids are regarded those devices that are mostly mechanical and simple in design. In contrast high-tech aids are associated with complexity and sophistication in design and contain advanced technological feature.

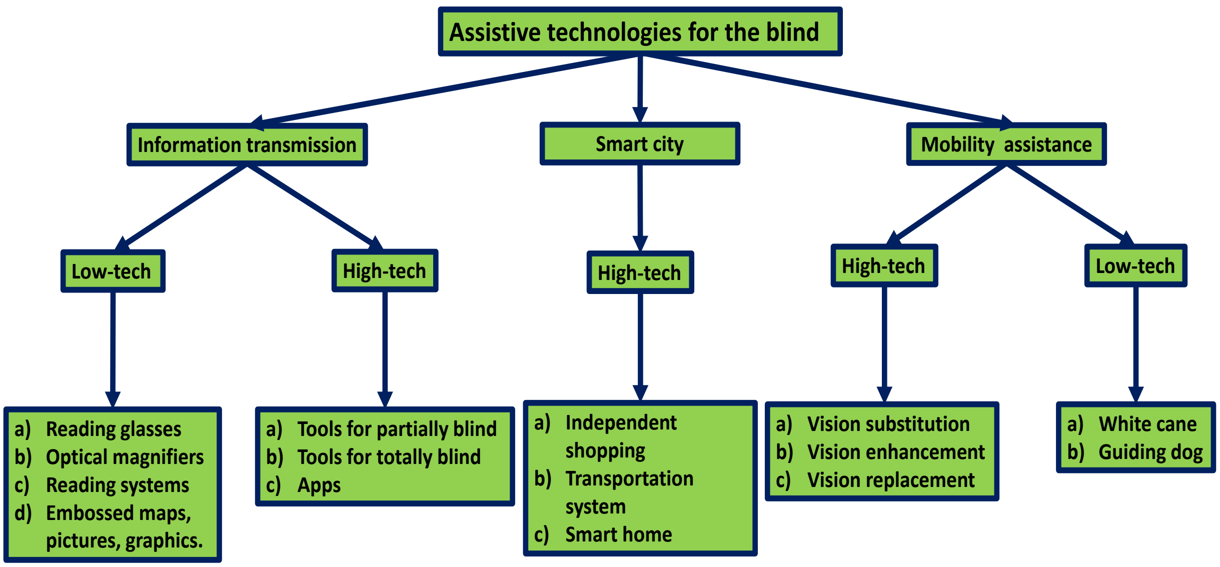



*Figure 8: Main categories and subcategories of assistive technologies for the blind.*

### 2.6.1. Information access

### 1. Low-tech aids

The low-tech information access aids involve tools that enable the access to different types of information, including textual information, graphical information such as maps and pictures and symbolic representation such as music and mathematics. Traditionally, reading glasses, optical magnifiers, reading systems and embossed maps, graphics and pictures are utilized to provide VIP with such information, with the reading systems being the most prevalent form of information access in totally blind people. The main reading systems are:

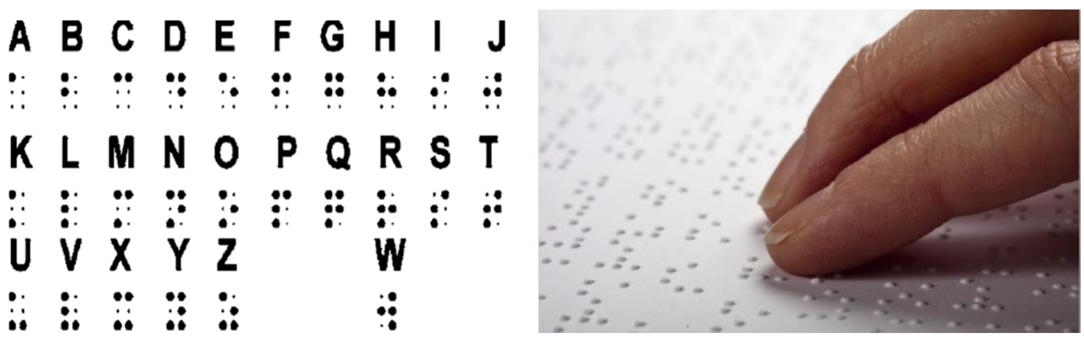
#### i) Braille reading system

Braille is raised dot embossed alphabet. It was invented by Louise Braille in the 19$^{th}$ century and today is recognize as the international standard writing and reading for the blind and deafblind people. Braille who was blind himself created the alphabet as an improvement to the night writing which was a tactile military code developed by Charles Barbier in response to Napoleon's demand for a mean for soldiers to communicate silently at night and without light. Alphanumeric characters and other symbols are represented by an arrangement of six raised dots (6-dot cell) arranged in two vertical columns of three dots each (Figure 9.a.). The presence or absence of particular dots marks each character and the possible combinations are 64. The interpretation of tactile characters is done using the fingertip as the inter-dot spacing is perfectly adapted to it (Figure 9.b). There are two types of Braille encoding [5, 52]:

- **Grade 1**: is a simple letter-by-letter transcription of text used for basic literacy.
- **Grade 2:** employs contractions in which one character represents several letters and is used usually advanced readers.

Despite the fact that the Braille reading system has greatly benefit blind people, it is important to mention that literacy rate among blind people is quite low especially among late-blind. The reasons for this are mainly attributed to the following factors [53]:

- Time consuming process.
- Decline in tactual acuity in older age.
- Higher demand for short-term memory.
- Lack of motivation.




a) b)

*Figure 9: a) Letters in Braille, b) A blind person reading Braille.*

### ii) Moon reading system

The second reading system is Moon (Figure 10) which was develop 1847 by Dr William Moon. The main advantage of Moon is that letters are similar to ordinary letters and therefore can be learned easier by people who have previously read visually. However, Moon is not popular due to the fact that writing in Moon occupies a lot of space compered to Braille, thus leading to a significant increase in the production cost of books [8].

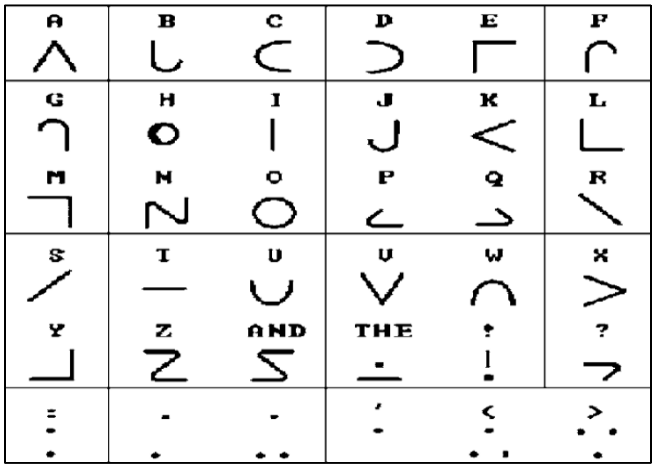



*Figure 10: Moon alphabet.*

## 2. High-tech aids

High-tech devices are aimed at overcoming the accessibility barriers in education, employment and recreational activities. In effort to accomplish this goal cutting-edge science and technology are incorporated in tools dedicated to support VIP in accessing information and communication technologies such as televisions, computers, the internet, telephones and smartphones. Based on their working principles and severity of visual impairment of the people that they serve high-tech tools are categorized in:

### i) Tools for partially blind

Usually, these type of tools are represented by the electronic alternatives to optical magnifiers the portable electronic vision enhancement systems (p-EVES) (Figure 11) which initially were termed as closed-circuit televisions (CCTVs) because of the direct cable link between the camera, imaging system and monitor viewing system. Similarly, to optical magnifiers their main goal to maximize the remaining sight. However, in comparison to optical magnifiers p-EVES seem to demonstrate numerous advantages such as greater magnification, binocular viewing, longer duration of reading, more natural working distance, which in turn leads to better posture, reduced aberration, and image manipulation (contrasts reversal or enhancement, introduction of artificial color etc.). Despite the aforementioned advantages there is plenty of room for improvements in order to overcome some key shortcomings associated with the cost and the longer-term performance [8, 49,54-55].

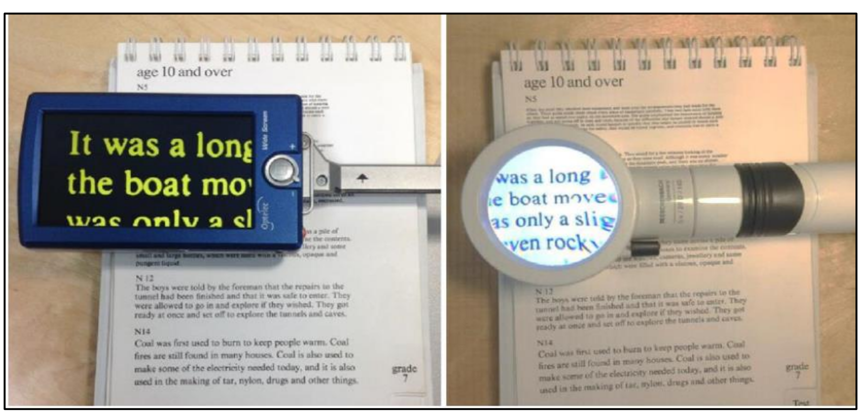



*Figure 11: Comparison of a p-EVES (left) with a optical magnifier.*

**ii) Tools for totally blind**

The main working principle of these tools is based on the conversion visual information into tactile and audio form**.** The most popular of them are [**49, 50**]:

- Advanced Braille tools e.g. Braille printer, Braille computer interfaces such as Braille mouse, keyboard and monitor, Braille refreshable display (Figure 12) Braille note-taker, Text-to-Braille translation software, Braille training software etc.
- Text-to-speech readers e.g. audiobooks.
- Portable reading devices.
- Voice recognition software e.g. voice command for mobile phones.

*Figure 12: Braille refreshable display.*

**iii) Apps for blind and visually impaired people** [**49, 50**]

- Magnification apps, which utilize the phone camera as a magnifying glass.
- Color detection apps, which use the camera to identify and speak the name of the color of an item.
- Money identification apps, which use the camera to identify the value of a note.
- Object identification apps, which use the camera to identify objects, also by reading labels and barcodes.
- Mobile apps that help disable people to use the public transportation.
- Crowdsourcing apps such as “Be My Eyes” which enable sighted individuals to help visually impaired people via web-based platforms. Usually, photos taken by blind people are send among anonymous web volunteers who describe what they see.
- Location and GPS apps such as Seeing Eye GPS or BlindSquare tailored to the needs of blind people.
- Braille apps, which teach Braille and allow typing Braille on the touchscreen.

### 2.6.2. Smart city

Recent advances in the network infrastructure along with the invention of smartphones and continuous evolution in areas such as Internet of Things (IoT), cloud computing, Artificial intelligences (AI) and robotics have created a fertile ground for development of smart cities that harness these technologies to empower VIP. Development of smart cities regarding VIP has been focused on three main areas [50, 56]:

**i) Independent shopping**

Shopping centers present an enormous challenge to VIP. In order to facilitate independent shopping various devices that leverage Radio Frequency Identification (RFID) technology are created to assist VIP in navigation of stores and identification of products. In the context of general shopping scenario (Figure 13) RFID tags are attached on the store's floor and on products and communicate via radio waves with a RFID reader embedded in the tip of white cane, which is connected via Bluetooth to blind person's smartphone that act as control station. Verbal instruction provided by headphone connected to the smartphone are used to guide blind person within the store. Moreover, information regarding products are transferred from RFID tags to the smartphone which forwards it to the RFID server. Finally, these information return to the smartphone and are announced in form of voice messages to the blind person.

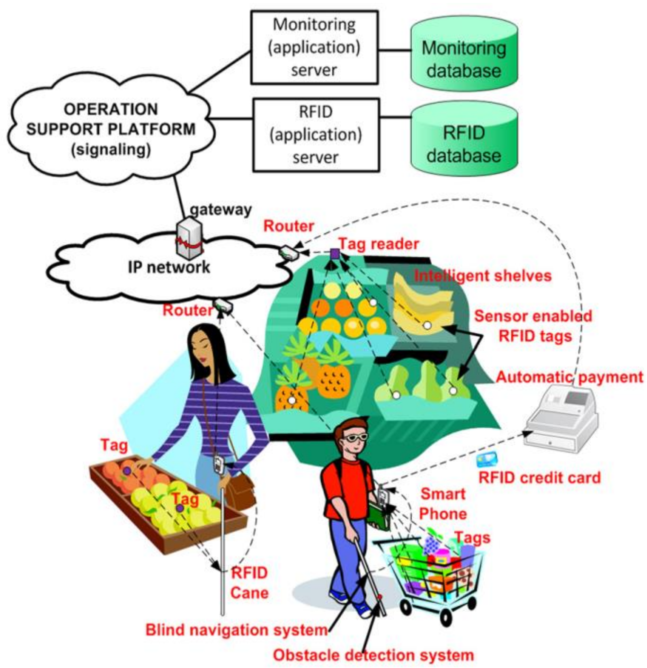



*Figure 13: Shopping scenario.*

**ii) Transportation system**

Another important features of smart cities is the development of a smart transportation system which will mitigate the challenges that VIP face when accessing public transportations means. Smart solution regarding public transportation has been focused on the development of systems that can help VIP to identify bus stops, be notified about bus arrivals and be guided towards vacant seats. Furthermore, another area that is gaining more and more ground is the design of self-driving cars that take in consideration the needs of VIP .The most noticeable examples are Google's self-driving car and Tesla's self – driving and collision detection system.

### iii) Smart homes

Smart homes as a vital part of smart cities need also to be equipped with smart solution for the VIP. The primary purpose of smart homes is to safeguard users' well-being and to provide a higher degree of independence through the use of intelligent technologies that are able to provide health monitoring and remote control of household appliances.

Throughout the years various systems have been proposed, some of the noticeable works that have been a source of inspiration for the development of our home assistance system are presented in [50] and [56]. Usually such systems utilizes various sensors and actuators that are embedded within the home environment, goods and appliances. For instance, various sensors can be distributed around the home to keep track of various parameters such as water leakages, fire, people's presence, temperature etc. Information from the sensors are accumulated on local or cloud-based server where are processed and checked if a rule violation occurs. In case of a violation an appropriate actuator is triggered. Smart switches and motors can be implemented to remotely control of lights, windows, doors and kitchen appliances. Moreover, a master-slave RFID architecture (Figure 14) can be employed to keep track and control of washing machine, fridge and oven. For instance, regarding the fridge, RFID tags attached to food items contain information about their nutritional values and these information can be accessed by the slave readers in the fridge which can forward them to master reader in the kitchen to suggest cooking recipes based on resident's preference and health condition. Regarding the healthcare of VIP smart devices can be used to identify medication and to read aloud prescription labels and also various wearable sensor such as smart ECG vests can be implemented to monitor vital signs.

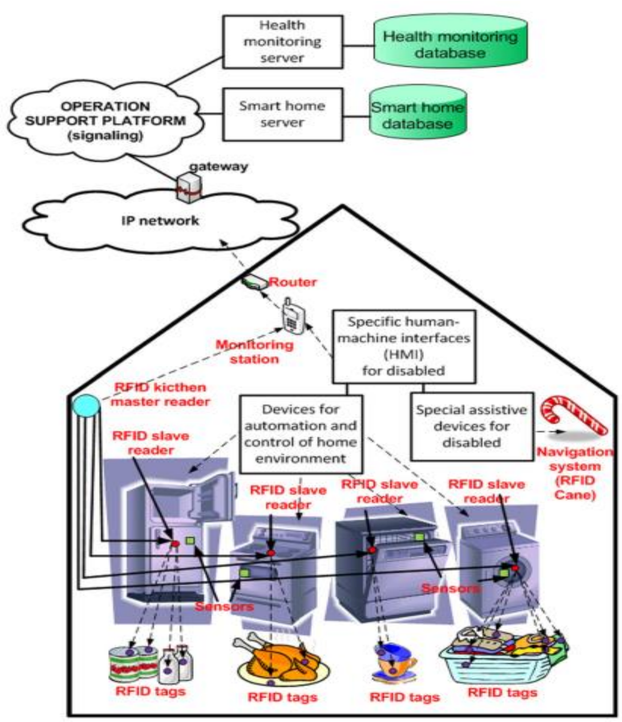



*Figure 14: Smart home Scenario.*

**Challenges in development of smart cities**

Despite the enormous efforts in development of sophisticated smart cities there are plenty of issues that need to be addressed. These issue concern mainly the safety and the privacy of users and the increased vulnerability to cyber-attacks.

## 2.6.3. Mobility aid

### 1. Low-tech aids

This category involve traditional navigation tools used by the blind people to navigate their surrounding environment. The most popular of them are white canes and guiding dogs.

#### i) White cane

The cane or walking stick (Figure 15) has been used for centuries as tool for the mobility of blind people, however its usage has become prevalent only after the Second World War. A blind person use the walking stick to avoid the nearby obstacle in front of him/hers by waving it from side to side. The main requirements regarding its basic features are the following [8]:

- The cane should be intuitive in use, cost-effective and maintenance free.
- The color of the cane should be white in order to indicate that the user has poor sight.
- The construction should be lightweight in order to be carried effortlessly but should have sufficient weight to withstand the breeze.
- The cane needs to be durable in order to withstand the pressure produced by the contact with the ground or objects.
- The length of the cane should be 1.0-1.5m in order to act as an extension of the user's arm and thus, to enable a preview of the ground for about 1m in front of him.
- The cane should conduct vibrations in order to transmit information to the user about the location and texture of objects.
- Lastly, the cane needs to provide auditory information (echolocation cues) that help the user to create a better understanding of the path ahead.

*Figure 15: A blind person using a white cane.*

### ii) Guiding dog

Along with the white canes traditionally guiding dogs (Figure 16) are used to assist blind people in the daily locomotion routine. Similarly to white canes the use of guiding dogs as mobility aids dates back in antiquity. The guiding dog and its owner need to be appropriately trained by experienced professionals and usually Labradors and German shepherds breeds are trained to become guiding dogs. The dogs is able to guide the blind person safely by avoiding possible obstacles and slowing down when the walking surface become rough or dangerous. Moreover, the guiding dog can obey commands and thus can help the human companion to find the entrance or exit of a building [8].

*Figure 16: Guiding dog in action in an urban environment.*

**Main drawbacks of white cane and guiding dog** [2, 8, 57]

Despite the help that white canes and guiding dogs offer to blind people they are often associated with numerous drawbacks that limit their performance and put blind people to great danger. The main drawbacks are listed below:

- White canes can detect obstacles within a short range about 1.5m, which may increase the risk of tripping or falling and can slow down the movement of the user.
- Users need extensive training to get comfortable with the device.
- Walking stick can cause damages to objects and can even hit a person in the way.
- For example, when the cane is in contact with the ground the hanging objects cannot be sensed.
- Objects above knee level cannot be detected and as a result the blind run in high risk of colliding with tree branches, overhanging wires, open windows etc.
- Guiding dogs and their owners needs to undergone extensive training sessions.
- Maintaining a trained dog can be very expensive (veterinary bills, food).
- Trained dogs have limited working life around 5 to 6 years.
- Blind people are unable to provide the necessary care to another living being.
- Access to trained dogs is challenging as their population struggle to catch up with the increased demand.

## 2. High-tech aids

Given the aforementioned shortcomings associated with the use of white canes and guiding dogs as mobility assistance tools several other more sophisticated and innovative tools that aim at insuring better safety and independence for blind people are created. Usually, based on their working principles they are divided in the following three categories:

**i) Vision enhancement**

In addition to reading some types of vision enhancement devices can be used in navigational tasks that require near resolution acuity. Similarly to a virtual reality systems in these devices the input is provided by a miniature head-mounted camera, the captured visual information is processed using an embedded image processing software, the user can adjust the functionality via handheld controller that is connected to the eyewear by an external wire and finally the output is presented on a head-mounted visual display. A prime example of vision enhancement devices is the eSight Eyewear (Figure 17) which has received approval by numerous organization and was launched commercially in 2013 and by March 2018 had more than 2000 partially sighted users [58, 59].

*Figure 17: eSight Eyewear (glasses and manual controller).*

**ii) Vision restoration**

Vision restoration is a treatment option for blindness which came as a result of efforts to find methods to restore the sight in individuals suffering from unavoidable blinding conditions such as retinitis pigmentosa (RP) and age-related macular degeneration (AMD) which degenerate significantly the retinal photoreceptors and block the normal flow of signals along the visual pathways [60]. Vision restoration involves the development of implantable electronic visual prosthesis (Figure 18) which aim at reactivation of visual sensation by electrically stimulating any part of the visual pathways. In order to create a neural stimulation micro-photodiodes or microelectrodes arrays are placed closely to the targeted neural cells beyond the damaged site. Usually, prosthetic device can be implanted in the visual cortex, on the lateral geniculate nucleus (LGN)), on the optic nerve or at the retina and based on the selected location the approaches for the development of visual prosthesis vary [61].

Regardless of the approach each devices consist of an external unit which includes a pair of glasses with a mounted camera that receive the visual information, a processing device that transform the received signals into electrical stimulation that then are send to the internal unit which is comprised of multiple microelectrodes that are located at the targeted part of visual pathways [61]. According to Mill et al. 2017 there are currently five retinal device that are approved or still in per-commercial development stages with the Argus II Retinal Prosthesis System and the Alpha IMSg Retina Implant AG being the most promising. At present the success of visual prosthetic devices has been very limited as their resolution is low due to the fact that they allow only the perception of spots of light and high contrast edges and thus the recognition and location objects is not feasible. Characteristic is the fact that the best visual acuities in ARGUS II and Alpha IMS clinical trials were 20/1260 and 20/546 respectively, which is far away from the visual acuity which is required to recognize shapes, objects and letters. In addition to the low resolution visual prosthesis are faced with numerous other challenges associated mainly with the complexity of surgical procedure, the high cost, and the biocompatibility and long-term viability of stimulating electrodes. Despite all these challenges, thanks to the relentless efforts from several research groups around the world the field visual prosthesis will gain further ground and eventually will optimize and adapt to satisfy the needs and desires of blind individuals [60-62].

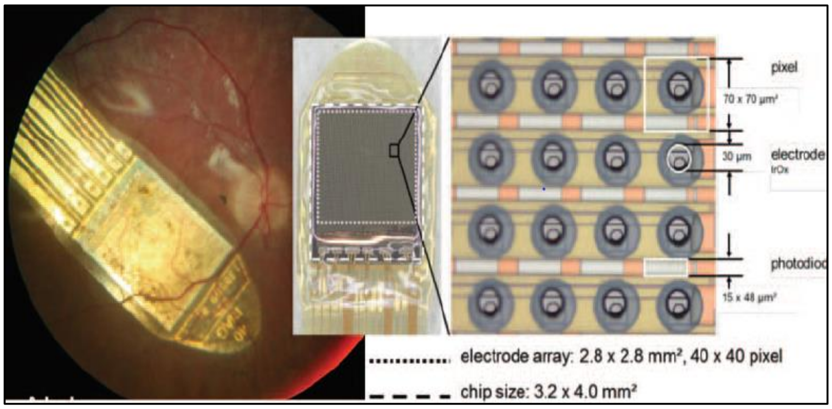



*Figure 18: Fundus picture of a patient with a subretinal implant.*

### iii) Vision substitution

Vision substitution devices assist blind individuals to navigate their path by exploiting nonvisual senses such as hearing or touch or a combination of them. According to [50, 59, 63] vision substitution devices are dived in three subcategories:

a) **Electronic travel aids (ETAs):** These are devices that receive information about the environment using various obstacle detection sensors and transfer them to the user through nonvisual senses. Usually, ETAs collect information from the surrounding environment via either laser scanners, cameras, infrared sensors or ultrasonic sensors and inform the user using auditory or tactile feedback or both and can be placed in different body areas such as fingers, hands, wrist, abdomen, chest, feet, tongue, ear etc.
b) **Electronic orientation aids (EOAs):** These are devices that provide blind people with direction during the travel.
c) **Position locator devices (PLDs):** These are devices that use GPS technology to determine the location of its holder.

## 2.6.4. Obstacle detection sensors embedded in ETAs.

Obstacle detection sensors are able to determine the proximity of obstacles without any physical contact. The most popular of them are the ultrasonic sensor, infrared (IR) sensor and laser range finder. Each sensor has its unique characteristic and working principles and the selection of the most suitable depends on features such as measurement range, accuracy, cost, weight, size and energy consumption. To provide some guideline is the selection of the right sensor a comparison of their working principles, advantages and disadvantages is presented in the following paragraphs [64-65].

**a) Ultrasonic sensors:** The ultrasonic sensors (Figure 19) emit high-frequency (>20 kHz) sound waves which are beyond human hearing capabilities to sense the distance to objects. The emitted sound waves are reflected back when come in contact with objects and the time between emission and reception is used to measure the distance. Ultrasonic sensors are cost-effective and have long measurement ranges. Experimental results suggest that the detection accuracy of ultrasonic sensors is not affected by factors such as dust, smoke, lighting condition and also the material and color of the object. Moreover, they can successfully detect transparent objects such as glass and water that are invisible for light-based sensors. However, ultrasonic sensors face difficulties in detecting objects that have mirror like surfaces and are sensitive to parameters such as ambient noise, temperature and humidity which cause changes in the velocity of ultrasonic wave.

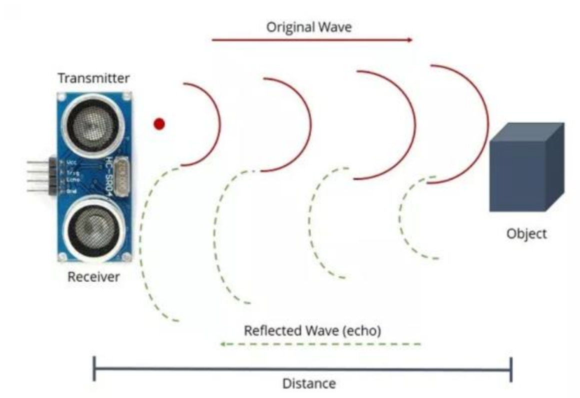
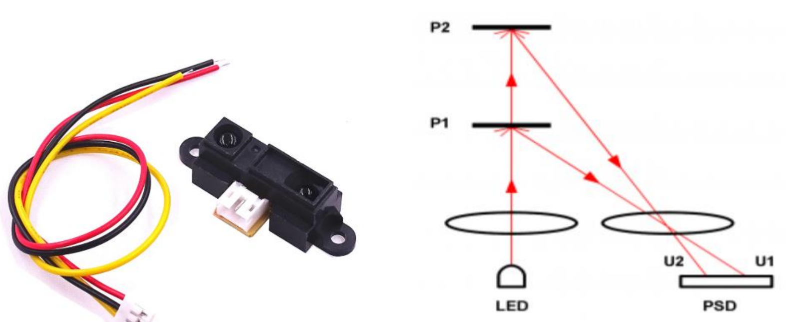



*Figure 19: Working principle of ultrasonic sensor.*

**b) Infrared (IR) sensor:** The IR sensor (Figure 20.a) works based on the principle of triangulation; measuring the distance based on the angle of the reflected beam. The sensor is comprised of a LED that act like an IR source and emits beams of light with a wavelength in the range of 760nm. Once the beams hit an object are reflected back and are detected by the IR detector which is a photodiode. An illustration of the working principle is provided bellow (Figure 20.b).




a b

*Figure 20: a) IR distance sensor b) Working principle*

IR sensors are inexpensive and provide a high resolution with quicker response time compared to ultrasonic sensors as the speed of the light is much quicker than sound. In addition, are small in size and in contrast to ultrasonic sensors are able measure the distance of objects that have complex surfaces. However, IR sensors have a limited detection range (<80cm) and struggle to detect objects with transparent and not flat surface. The readings of the sensor are affected by the ambient light and object's color and also the sensor must be pointed directly to the object as the beam is very thin.

c) **Laser**: Similarly to IR sensors laser sensors (Figure 21) work also based on the triangulation principle, but they use laser light instead. Laser sensors exhibit higher detection accuracy and larger measurement range (up to 30 meter) than ultrasonic sensors or IR sensors. Furthermore, they are suitable for fast-moving objects as they have a quick response and also due to low energy consumption can be used in application that require long term usage However, due to advanced electronics they cost is substantially higher and similarly to IR sensors cannot detect all types of materials. Moreover, the visible light of laser sensors can be disturbing to some people in crowded environments.

*Figure 21: Laser distance sensor.*

### 2.6.5. Recent mobility aid devices

Below are briefly presented some of the most representative works in the field of mobility aid an devices which have been a source of inspiration for our designs.

Wahab et al. [66] present the development of a cane named Smart Cane that is able to detect obstacles in front of the user and alert him/her through voice messages and vibration. Smart Cane (Figure 22) is a portable device that consist of ultrasonic sensors used to detect objects, microcontroller used for information processing, vibrator motor and buzzer used for user warning and water sensors that detect the presence of water. According to the authors the device has successfully passed the test that underwent and thus can accurately detect objects and provide the necessary feedback. In addition, it is recommend that future designs need to include a power supply meter for the monitoring of power status and a buzzer timer to specify the duration of the period that the buzzer is activated.

*Figure 22: Smart cane prototype.*

Garcia et al. [67] have developed the Electronic Long Cane (Figure 23) a device that detects physical barriers above waistline based on echo detection and gives tactile feedback in the form of vibration. The frequency of tactile feedback increases as the distance from the obstacle decrease. The device has an ergonomic design and it is portable. An electronic circuit is embedded in the cane and consist of ultrasonic sensor that act as obstacle detector, microcontroller, vibrator and 9 Volt battery. Tests revealed that the device can efficiently detect objects above waistline but lack orientation function.

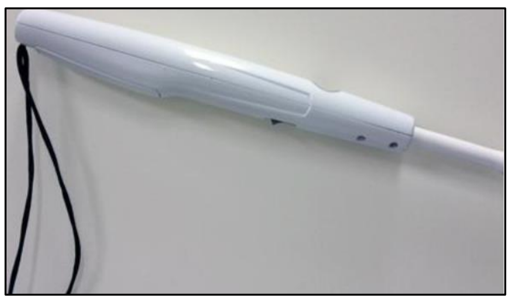


*Figure 23: Electronic Long Cane.*

Kamaludin et al. [68] present an affordable hand-mounted device (Figure 25) that can improve the mobility of VIP. The casing of the device was created using a 3D printer and the device consist of the two ultrasonic sensors, two servo motors, two buzzers, a microcontroller (Arduino Pro Mini) powered by a Lithium Polymer (LiPo) rechargeable battery and an external 5V voltage regulator that adjust the voltage from the battery to 5V. The positive feedback from the majority of volunteers that participated in the tests indicate that the device have achieved its goals in some degree.

*Figure 24: Hand-mounted device.*

Mekala et al. [69] present a lightweight wearable glove (Figure 26) to aid VIP. The device consist of microcontroller (Arduino), 9-volt battery, ultrasonic sensors, IR sensor, vibration motor and Bluetooth module. Ultrasonic sensors are placed on the right and left side of the glove so that the user can detect obstacles from both left and right directions. The signal from the ultrasonic sensors is send to vibrator motors attached to each finger and the intensity of vibration indicates how far or near the objects are. Moreover, the device can help blind people to identify the shapes of printed objects both black and white or grayscale. To achieve this IR sensors are placed at the tip of the four fingers and when the fingers are moved over a dark surface the reflected infrared rays activate the vibrating motor of corresponding finger, whereas no vibration is felt when the rays are reflected form the white surface. A Bluetooth module can be connected to the Arduino microcontroller in order to switch modes using mobile apps. Regarding future improvements the authors suggest the addition of waterproof cover and more operating modes.

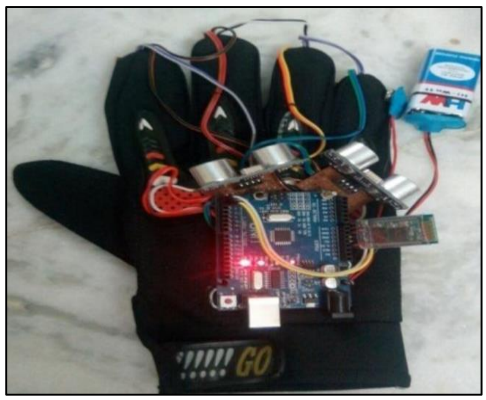


*Figure 25: Wearable glove for the blind.*

Jones et al. [70] from MIT present a tactile display embedded in vest that is placed around the lower back (Figure 27). The device is hands free and the tactile display consists of a 4 × 4 array of vibrating motors that are wirelessly controlled. The motors for the display were carefully selected to be small, lightweight, robust and safe to worn on the body. The conducted experiment revealed that the users could recognize the tactile patterns with almost perfect accuracy.

*Figure 26: Tactile vest for the blind.*

# Chapter 3: Hardware and software analysis

This chapter is divided in two main sections. The first section involves the mobility aid system and the other the smart home assistance system. Each section is accompanied by an overall block diagram of the proposed system and a detailed description of the utilized hardware and software.

## 3.1. Mobility aid system

### 3.1.1. System Architecture and working principles

The proposed mobility aid system consist of four main parts, namely, control unit, obstacle detection unit, alarm unit and power supply, which are integrated as shown in Figure 27. In next section, we detail each of these parts.

The system is designed to be wearable in form of a wrist or hand mounded glove embedded with two ultrasonic sensors (US) that measure the distance from nearby obstacles. The S1 sensor is used to detect the obstacles that are in front of the user from the leg to the chest region and the other sensor (S2) aims at detecting obstacles at head region. The US sensors transmit ultrasonic waves which get reflected once they reach an object. The reflected signal (echo) is detected by the US sensors which are connected to the Arduino Nano. Then, the Arduino calculate the distance from the object by evaluating how long it takes for the echo to return to the sensor. If the obstacle is not with a predefined distance the circuit does not trigger an action. If the feedback signal indicates that the obstacle is within detection range the user is alerted through two beeping sounds of different intensity, depending on the sensor that makes the detection. The low intensity beeping sound is triggered when the S1 sensor detects an object whereas the high intensity beeping sound is produced when the detection is made from the S2 sensor.

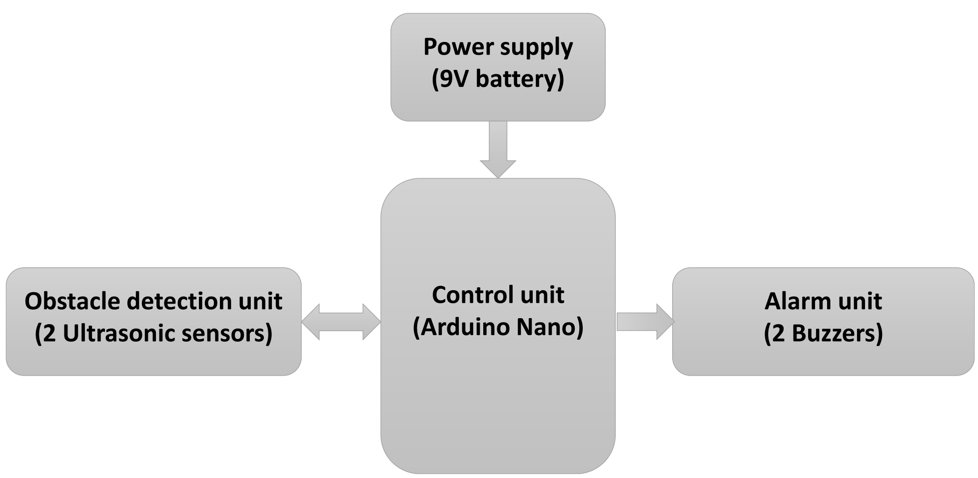



*Figure 27: Block diagram of mobility aid system.*

### 3.1.2. Hardware selection

The selection of the electronic components incorporated in our design was made by bearing in mind the objectives discussed in Section 1.3.

### i) Control unit

The whole system is commanded by an Arduino Nano (Figure 28) which is a small, compatible and breadboard friendly board based on ATmega328 microcontroller with functionalities similar to that of the Arduino Uno. However, in contrast to UNO board it lacks the DC power jack and works with Mini-B USB cable instead of a standard one. Furthermore, the UNO board is available in PDIP (Plastic Dual-In-line Package) form with 30 pins and the Nano is available in TQFP (plastic quad flat pack) with 32 pins. The extra 2 pins of Nano board serve for the ADC functionalities, while UNO has 6 ADC ports but Nano has 8 ADC ports. Given its small size and flexibility can be easily integrated into wide range of applications where the size electronic components is of great concern such as wearable devices, robotics etc. Below (Table 1) are outlined its main specifications [71-72].

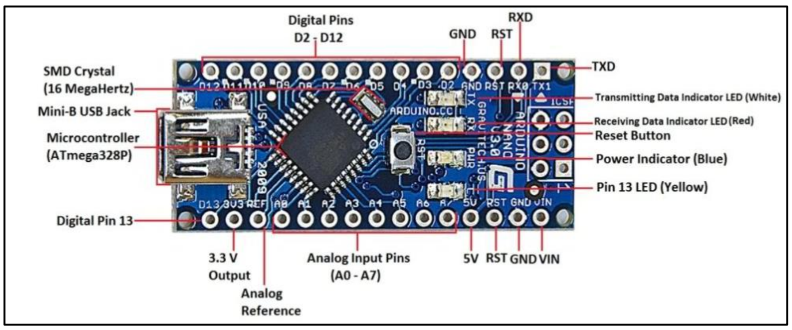



*Figure 28*: Arduino Nano Pinout Description.

**Table 1: Arduino Nano specifications**

| | |
|---|---|
| Software | Arduino IDE |
| Microcontroller | ATmega328 |
| Operating Voltage | 5V |
| Input Voltage (recommended) | 7 – 12 V |
| Input Voltage (limit) | 6 – 20 V |
| Digital I/O Pins | 14 |
| PWM Digital I/O Pins | 6 |
| Analog Input Pins | 6 (A0-A5) |
| DC Current per I/O Pin | 40 mA |
| DC Current on 3.3V Pin | 50 mA |
| Flash Memory | 32 KB (2KB used by Bootloader) |
| Flash Memory for Bootloader | 2 KB |
| SRAM | 2 KB |
| EEPROM | 1 KB |
| Clock Speed | 16 MHz |
| Communication | IIC, SPI, USART |

### a) Arduino Nano memory features

- **2KB of SRAM** (Static random access memory) is where the variables are created and manipulated when the program runs. The SRAM is volatile and will be lost when the power is disconnected.
- **32KB of flash memory** is where the program is stored. The program is executed from the flash memory but it cannot be modified. In order to modify it the program must first be copied into SRAM Flash memory. The Flash memory is non-volatile meaning that the program remains after the board is powered off. Furthermore, has a finite lifetime of about 100,000 write cycles.
- **1KB of EEPROM** is the memory space where long-term information are stored. Similar to flash memory is non-volatile and it has a finite lifetime of about 100,000 write cycles.
- **External memory:** When application require more memory space additional memory can be added externally using Mirco SD card in the boards to make them store more information.

### b) Arduino Nano specials pins and features

**Digital pins:** There are 14 I/O digital pins incorporated in the board that allow the connection of any external circuit with the board. These pins operate at 5V and can tolerate current of 20mA to 40mA. In order to limit the current each pin has an internal pull-up resistor with a resistance of 20-50KΩ. Depending on the requirements of the applications pins can be configured as input or output and can be either ON or OFF. ON means that are in a HIGH voltage state of 5V and OFF they are in a LOW voltage state of 0V. When digital pins are configured as OUTPUT, they are set to 0 or 5 Volts. When the digital pins are configured as input, the voltage is supplied from an external device. This voltage can vary between 0-5 volts which is converted into digital representation (0 or 1) using predefined thresholds. Some of these pins have specific function as listed below:

- **Serial Pins 0 (Rx) and 1 (Tx):** Rx and Tx pins are used to receive and transmit TTL serial data. They are connected with the corresponding ATmega328P USB to TTL serial chip.
- **External Interrupt Pins 2 and 3:** These pins can be configured to trigger an interrupt on a low value, a rising or falling edge, or a change in value.
- **PWM Pins 3, 5, 6, 9 and 11:** These pins provide an 8-bit PWM (Pulse Modulation Mode) output.
- **SPI Pins 10 (SS), 11 (MOSI), 12 (MISO) and 13 (SCK):** These pins are used for SPI communication.
- **In-built LED Pin 13:** This pin is connected with a built-in LED.

**Analog pins:** The Nano board contains 6 analog pins which are marked as A0 to A5 and are capable of reading voltages within the range of 0 to 5 volts. Using the build-in 10-bit resolution ADC, analog signals are represented in digital values within the range of 0 to 1023.

**VIN pin:** In addition to the USB port the device can also be powered through the VIN pin using voltages between 7 and 20volts.

**5V pin:** Using this pin the UNO can supply the connected external circuits with 5V.

**3.3V pin:** it provide the 3.3 volts supply generated by the on-board regulator.

**GND pins.** Ground pins.

**Reset.** The reset pin is incorporated on the board to resets the program running on the board. Pushing this pin will clear everything up in the program and starts the program right from the beginning.

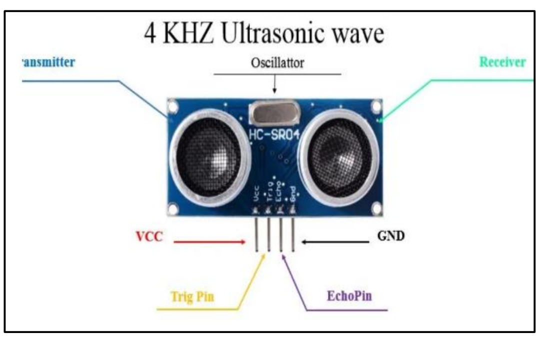
### ii) Obstacle detection unit

As mentioned in section 2.6.4 the detection of obstacle can be accomplished using various sensors. Based on their distinctive characteristics and limitations was concluded that ultrasonic sensor is the more suitable option for our application as it offers the best cost-performance ratio and meets successfully the objectives set in section 1.3. The HC-SR04 ultrasonic sensor (Figure 29.a) that is utilized in our mobility aid device uses an oscillator to generate 40 kHz ultrasonic sounds and can both transmit and receive ultrasounds as the transmitter and receiver are embedded together in a single unit. Both the transmitter and the receiver are made of piezoelectric crystals (Figure 29.b). When electric energy is applied on the transmitter piezoelectric crystals convert electrical signals into ultrasounds whereas when ultrasounds are reflected back and come in contact with the piezoelectric crystals of the receiver the ultrasounds are converted into electrical signals.

The HC-SR04 sensor is traditionally used as proximity sensor. For instance, is often utilized in car parking and robot navigation technology. In addition, it can also be used as level sensor in liquid detection, monitoring and regulation application [73].

**HC-SR04 sensor specifications and pins description**

- **VCC** → Power supply connection (5 Volt).
- **GND** →Ground pin.
- **Trig** → Triggering Input Pin. 10uS TTL Pulses
- **Echo** →This pin produces a pulse when the reflected signal is received. The pulse is proportional to the distance.



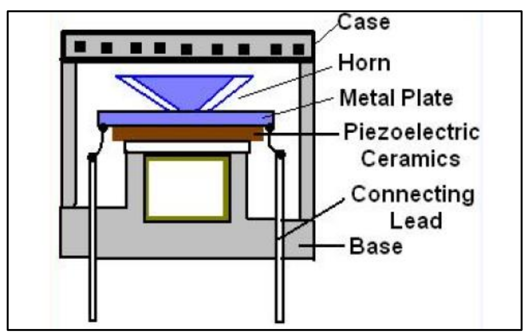




*Figure 29: a) HC-SR04 ultrasonic sensor description, b) Construction of ultrasonic sensor*

**Table 2: HC-SR04 specifications**

| Electrical parameters | Value |
|---|---|
| Operating Voltage | 3.3Vdc ~ 5Vdc |
| Quiescent Current | <2mA |
| Operating Current | 15mA |
| Operating Frequency | 40KHz |

| | |
|---|---|
| Operating Range | 2cm ~ 400cm ( 1in ~ 13ft) |
| Sensitivity | -65dB min |
| Sound Pressure | 112dB |
| Effective Angle | 15° |
| Connector | 4-pins header with 2.54mm pitch |
| Dimension | 45mm x 20mm x 15mm |
| Weight | 9g |

**Sensor operation using timing diagram**

- Initially, in order to generate ultrasounds the Trig pin needs to be set high. To achieve this a 5 Volt pulse of at least 10 µS (10 microseconds) in duration is applied to the Trigger pin (Figure 30).
- In response to the applied pulse the sensor will transmit a sonic burst of eight pulses at 40 kHz and will wait for the reflected ultrasonic burst. This 8-pulse pattern makes the "ultrasonic signature" from the device unique, allowing the receiver to discriminate between the transmitted pattern and the ultrasonic background noise.
- If no obstacles are encountered within the range of the sensor, pulses will not be reflected back and the Echo signal will timeout after 38 ms (38 milliseconds) and will return low.

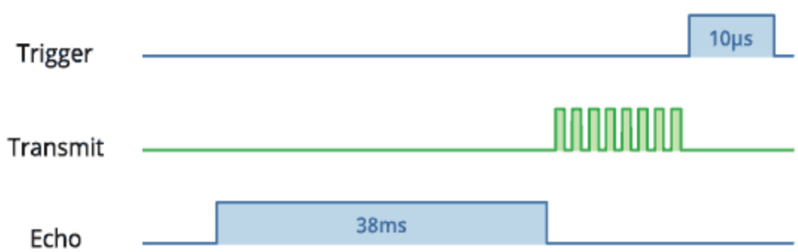
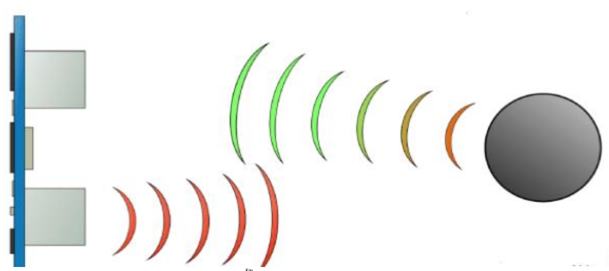



*Figure 30: Timing diagram in the case of no obstacle detection.*

- If pulses are reflected back the Echo pin goes low as soon as the signal is received. This produces a pulse whose width varies between 150 µsec to 25 msec, depending upon the time it took for the signal to be received (Figure 31).



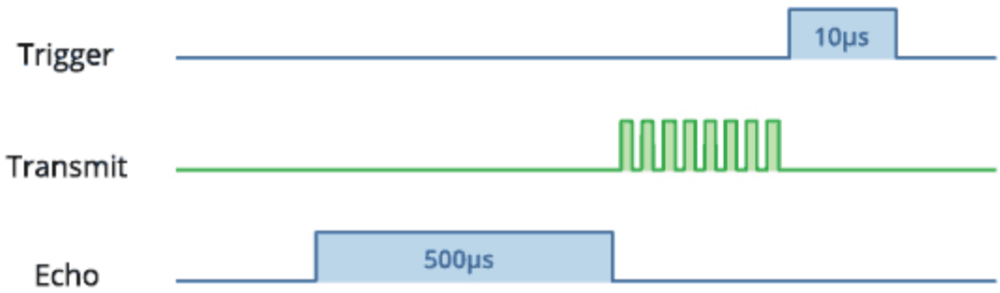



*Figure 31: Timing diagram in the case of obstacle detection.*

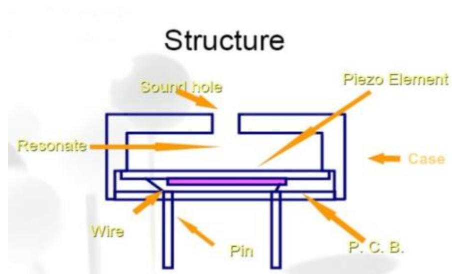
Using the width of the received pulse the distance to the reflected object can be calculated. Given that the pulse indicates the time between the emission and reception of the sound the distance can be calculated by dividing the result in half. Therefore the distance can be calculated using the following equation:

$$D = \frac{T \cdot C}{2} \quad Eq. 2$$

where D is the distance, T is the time between the emission and reception, and C is the sonic speed (340 m/s or 0,034cm/µs).

### iii) Alarm unit

In our application two buzzers (Figure 32) are used to alert blind people when the ultrasonic sensors detect any obstacle. A buzzer is an audio signaling device that may work based on mechanical, electromechanically or piezoelectric principles. The piezoelectric buzzer can be easily used on breadboard as it has a compact 2-pin structure. At the heart of the buzzer is the piezoelectric audio transducers which is composed of piezoelectric ceramic element in conjunction with a metal plate. The generation of the beeping sound is based on the reverse piezoelectric effect. More specifically, when current is applied to the buzzer the metal plate vibrates due to the expiation and contraction of the element, resulting in production of an audible sound [74].




a) b)

*Figure 32: Piezoelectric buzzer: a) external structure b) Internal structure*

### iv) Power supply

The prototype is powered using a 9Volt non-rechargeable battery (Figure 33.a) which is attached to the Arduino board using a cable connector (Figure 33.b).


a) b)

*Figure 33: a) 9Volt Battery, b) Cable connector.*

### 3.1.3. Software

#### a) Arduino IDE

The Arduino Nano is programmed in C/C++ language using the Arduino IDE software (Integrated Development Environment) which is compatible with common operating systems such as Linux, Windows, and MAX. The Arduino IDE can be downloaded freely from the official Arduino website: http://arduino.cc/en/Main/Software. Detailed instructions regarding its installation can be found in the following site: http://arduino.cc/en/Guide/HomePage. The main parts of the Arduuino IDE are presented below (Figure 34)

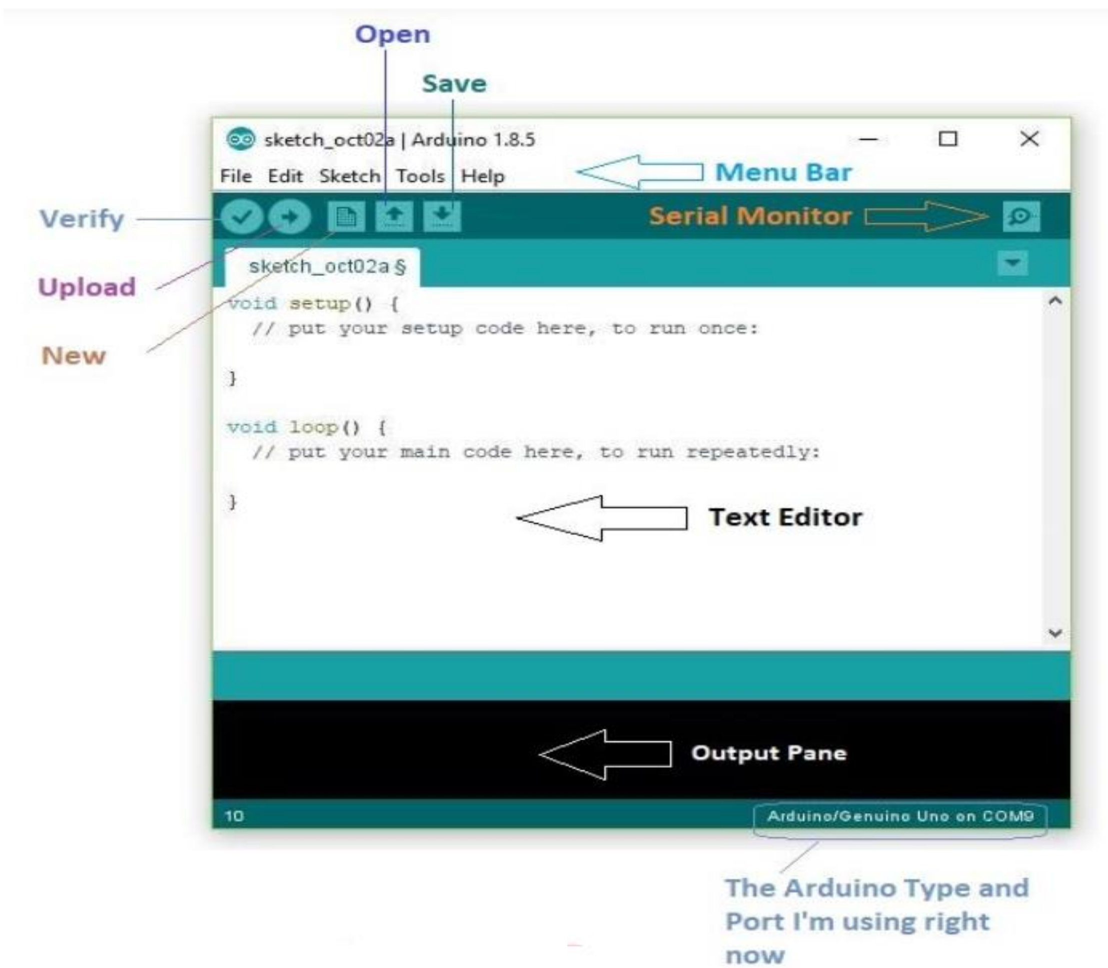



*Figure 34: Main parts of Arduino IDE.*

In order to upload the code to the Arduino board we need initially to connect it to a computer via an USB cable, then we need to make some adjustments. The first step involves the selection of the type of the board that we are using. The second step involves the selection of our computer's serial port to each the board is connected.
Arduino code is referred as sketch and is comprised of three main parts:

- **Variable declaration section:** In this part of the sketch are declared variables and they type.
- **Setup () function:** The setup () function is used to in initialize the variables, state of pins, classes etc. It runs only once, after each power up or reset of the Arduino board.
- **Loop () function:** The code written in the loop () function is executed repeatedly until the Arduino is switched off or reset.

### b) Code analyses

```
const int trigPin1=3;
const int echoPin1=4;
const int trigPin2=7;
const int echoPin2=6;
const int Buzzer1 = 2;
const int Buzzer2 = 8;
int, distance1; distance2;
long duration1; duration2,;
```

In the first lines of our Arduino sketch we declare all the variables that are used in our code. Initially, we define the name and the type of each variable and then we declare in which pin of the Arduino Nano are connected the two buzzers and also the Trig and Echo pin of each ultrasonic sensor. Regarding the type of the variable the majority of them are referred as **int** which stands for integer that is a whole number. The **int** variables use just two bytes of data for each number stored from the 1024 available bytes of storage on Arduino. Only variables **duration1** and **duration2** are characterized as **long** which is used for variable that store 32bits (4bytes). Furthermore, in some variables we notice the use of the word **const** which stands for constant and indicates that value of the variable cannot be changed.

```
void setup() {

  pinMode (trigPin1, OUTPUT); // Set the tringPin1  as output
  pinMode (echoPin1, INPUT); // Set the EchoPin1  as input
  pinMode (trigPin2, OUTPUT); // Set the tringPin2  as output
  pinMode (echoPin2, INPUT); // Set the EchoPin2  as input
  pinMode (Buzzer1, OUTPUT); // Set the Buzzer1  as output
 pinMode (Buzzer2, OUTPUT);  // Set the Buzzer2  as output
  Serial.begin (9600); // Start the serial communication

}
```

In the second part of the code we have the **setup ()** function which starts with the keyword **void** that indicates that the function does not return information to the function from which it was called. Moreover, we notice that the setup function uses two types of brackets with a different purpose each:

- Curly brackets **{}** are used to show the start and the end of the function.
- Normal bracket **()** are used for additional parameters. The setup function does not take any additional parameter, so is left empty.

Next, in the setup function we declare the mode of the digital pins. Depending on the function that we want to achieve digital pins can be used as INPUT or OUTPUT. In order to accomplish this we utilize the **pinMode** function which has the following syntax: pinMode (Pin, Mode);

- Pin: Arduino pin on which we wish to set the mode.
- Mode: INPUT, OUTPUT or INTUT_PULLUP

The two buzzers and the Trig pin of each ultrasonic sensor are configured to behave as output whereas the Echo pins of ultrasonic sensors set as an input. When a pin is configured as INPUT is set in high-impedance state and makes small demands on the circuit that it is sampling. This means that it takes very little current to move the input pin from one state to another and makes it useful for such tasks as reading information coming into the board, in our case reading pulses received from the Echo pin of the obstacle detection sensor. In contrast when a pin is configured as OUTPUT is said to be in a low-impedance state that enable it to supply a substantial amount of current (up tp 40mA) to other circuits. In our case this current is applied on the Trig pin in order to initiate the generation of ultrasonic sound waves and also is applied on the buzzer to trigger an alarm.

Furthermore, in the above lines of code we can notice the use of function **Serial.begin (9600)** which is used to print the acquired results to the Arduino IDE's Serial Monitor so we can view Arduino's output on the screen and debug if a false alarm is triggered. The number 9600 in parentheses indicates the speed of serial data transmission which is measures in bits per second (baud).

Lastly, the two slashes (**//**) that are seen in our code indicate the use of comments that can help in the better understanding of the code.

```
void firstsensor() { // Loop function for the first sensor.
  // Clears the trigPin1
    digitalWrite(trigPin1, LOW);
  digitalWrite (trigPin1, HIGH);
  delayMicroseconds (10);
  digitalWrite (trigPin1, LOW);
  duration1 = pulseIn (echoPin1, HIGH);
  distance1 = duration1 * 0.034 / 2;
 digitalWrite(Buzzer1, LOW);

     Serial.print("1st Sensor: ");
     Serial.print(distance1);
     Serial.print("cm    ");
```

```
  if (distance1 < 100) {  // check the distance for the in front obstacle
    digitalWrite (Buzzer1, HIGH);
  } else {
    digitalWrite(Buzzer1, LOW);
  }
}

void secondsensor(){ // This function is for second sensor.
    // Clears the trigPin2
    digitalWrite(trigPin2, LOW);
    digitalWrite (trigPin2, HIGH);
    delayMicroseconds (10);
    digitalWrite (trigPin2, LOW);
    duration2 = pulseIn (echoPin2, HIGH);
  distance2 = duration2 * 0.034 / 2;
  digitalWrite(Buzzer2, LOW);
      Serial.print("2nd Sensor: ");
      Serial.print(distance2);
      Serial.print("cm    ");

    if (distance2 < 70) { // check the distance for the overhanging obstacle
    digitalWrite(Buzzer2, HIGH);
  } else {
    digitalWrite (Buzzer2, LOW);
    }
}
```

After performing the tasks included in the setup function we continue with the third part of our code in which we have the **firstsensor** function and **secondsensor** function for each ultrasonic respectively. At the beginning of each function we clear the Tring pin of each sensor by setting it on LOW state for 2 μs. The 2 μs delay is achieved using the delayMicroseconds () function. In order to drive the **tringPin1** and **tringPin2** in LOW state we utilize the **digitalWrite** function that can set digital pins HIGH by sending 5V or LOW by sending 0V.

Using the same function we trigger the generation of ultrasounds by setting Trig pins in HIGH state for 10 μs. Next, the distance from the detected obstacles is calculated by initially reading the travel time of generated ultrasounds. The travel time is assigned to variables **duration1** and **durations2** and is acquired using the **pulseIn ()** function which takes two parameters the first is name of Echo pin and second is the state HIGH or LOW. In our case the state of the pin is HIGH which means that the function it will start timing after the pin has gone from LOW to HIGH state, then it will wait for the pin to go LOW when the sound wave will end which will stop the timing. The **pulseIn ()** function returns the length of the pulse in microseconds and the distance can be estimated utilizing the Eq.2 in which the duration is multiplied by 0,034cm/µs and divided it by 2. Finally, the value of the distance in centimeters is printed on Serial Monitor.

Once the value of the distance is calculated for each sensor the code checks if obstacles are within a predefined distance. The threshold distance for each sensor is decided based on human walking speed which is 4km/h=1m/s. According to experimental results presented in related works [75], the threshold distance need to be more than 1m in order to ensure the safety of blind people while using the navigation tool. Therefore, the threshold distance for both sensors is set to be 1.5m. When the measured distance becomes less than the threshold each sensor activates a different alarm in order to inform the user about the height in which the obstacle is encountered. Thus, the S1 sensor that is responsible for the detection of obstacles from ground level to chest level triggers the activation of the low intensity buzzer when the distance becomes less than the threshold. In contrast, the S2 sensor that is responsible for the detection of obstacles around the head region activates the high intensity buzzer when the distance becomes less than the threshold. The two buzzers are switched on by using **digitalWrite(Buzzer1, HIGH)** and **digitalWrite(Buzzer2, HIGH).**

```
void loop() {

Serial.println("\n");
firstsensor();
secondsensor();
delay(100);

}
```

The last part of the code involves the use of **void loop ()** function which is used to help the sensors' functions run repeatedly, so we can measure the obstacle person distance as it changes continuously.

## 3.2. Home assistance system

### 3.2.1. System Architecture and working principles

The home assistance system (Figure 35) consist of two parts, the voice notification device and the voice control device. The voice notification device aims at notifying the blind person about in which room is at the moment, the overcoming of specific threshold in the home temperature and the detection of fire in home. The detection these parameters is accomplished using various sensors that are incorporated the detection unit such as ultrasound sensors for detection of blind person's presence in each of home's rooms, temperature sensors for temperature monitoring and flame sensor in case of fire. When one of these sensors makes a detection the message generation unit of the device is activated and the appropriate voice messages is announced.

On the other hand, the voice control device utilizes voice messages to control various home items such as the lights which are represented in our prototype by LEDs and cooling system which is represented by a fan.

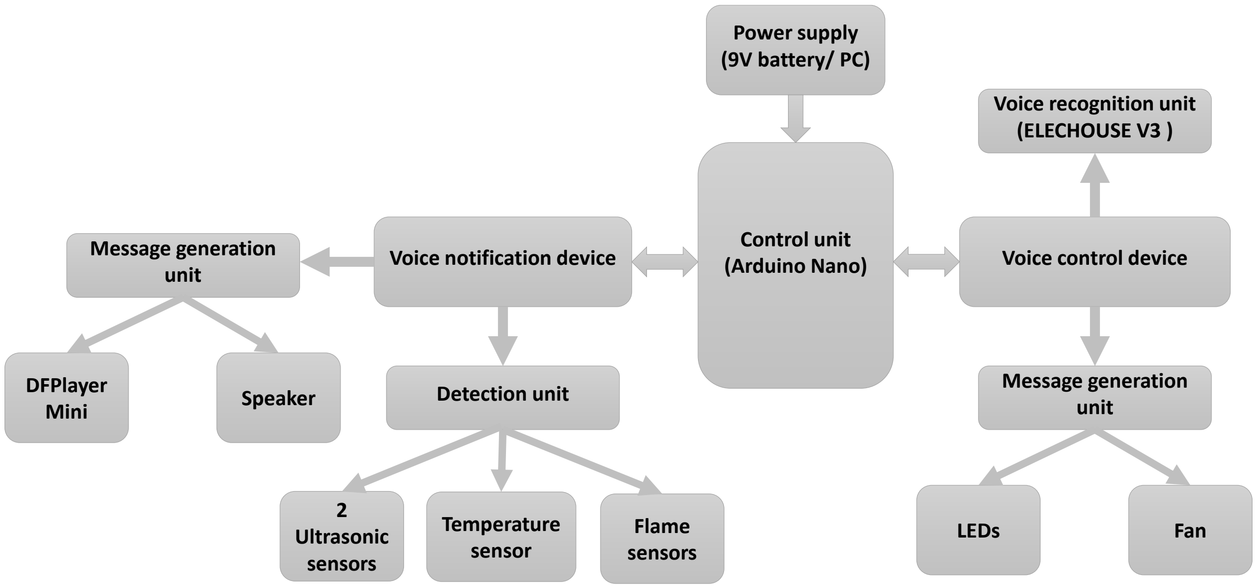



*Figure 35: Block diagram of home assistance system.*

### 3.2.2. Hardware analyses

#### i. Control unit

Similarly to the mobility aid system the control of the smart home assistance system is accomplished using Arduino Nano.

#### A) Voice notification device

#### ii. Detection unit

The detection unit is comprised by three types of sensors and each of them serves specific purposes such as detection of blind person's presence in each of home's rooms, temperature monitoring and fire detection. A detail analyses of each sensor is provided in the following paragraphs.

#### a) Ultrasound sensor

After examining the performance of various motion detection sensors we came the down to the conclusion the best performance in detecting user's presence in the rooms of the house is achieved using the ultrasound sensors similar to those that we incorporated to the mobility aid system.

#### b) Temperature sensor

The temperature in the home is monitored using the LM35 temperature sensor (Figure 36) which is a three terminal integrated-circuit temperature device with an output voltage linearly proportional to the Centigrade temperature. It can senses temperatures ranging from -55 degree Celsius to +150 degree Celsius and its output voltage increases 10mV per degree Celsius rise in the temperature. The sensor is easy in use as does not require any external calibration and can be powered using a 5V power supply [76].

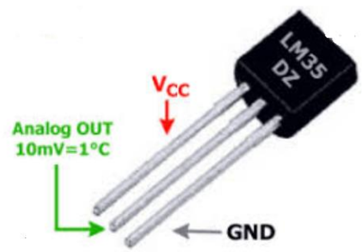



*Figure 36: LM35 pins diagram.*

#### c) Flame sensor

Fire detection is achieved using a three pin KY-026 flame sensor (Figure 37) which is comprised of the following main parts [77]:

- **Photodiode** which is placed in the front part of the module and is responsible for detection of radiation emitted by the fire which lays in the spectrum of infrared radiation.
- **Potentiometer** which is used to adjust the detection sensitivity of the photodiode.
- **LM393 comparator** which based on the signal that the photodiode receives is able to activate one of indicator LEDs and sets the digital output HIGH state.
- **2 indicator LEDs.** One of the LEDs is activated when the sensor is activated and the other is activated when fire is sensed.

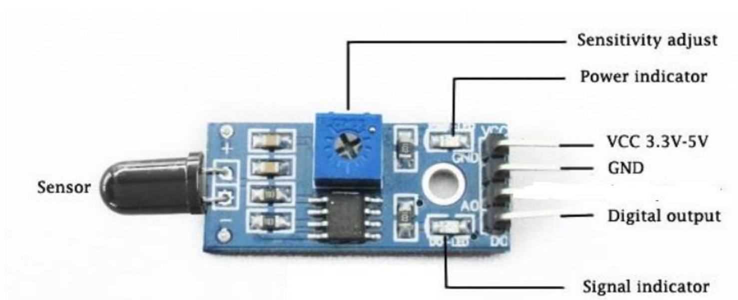



*Figure 37: Flame sensor.*

### iii. Message generation unit

#### a) DFPlayer mini

The announcement of the messages is performed using a DFPlayer Mini module (Figure 38) in combination with a speaker. The DFPlayer Mini (or) MP3-TF-16P module is a small and affordable MP3 module with inbuilt amplifier which can drive up to 3 watt loudspeaker. The DFPlayer mini module is the ideal choice in any project that requires sound or music and can be used as standalone module with a power source of 3.3V-6V, a speaker and push buttons or it can be used in combination with a microcontroller like Arduino or any other with UART Ports (RX/TX). Moreover, the module is equipped with a micro SD card slot and can support FAT16 and FAT32 file system with a maximum of 32GB for a TF card. The mp3 files that are stored in the SD card need to be placed in a folder that is named using 2 digits, for example “01”. In addition, files name need to contain 4 digits, for example, “0001.mp3”. After the 4 digits the audio file names can have any character, for example, “0001hello.mp3”. Further information regarding the specifications of the module can be found in its datasheet [78]. Below is provided a detailed diagram of the module’s pins.

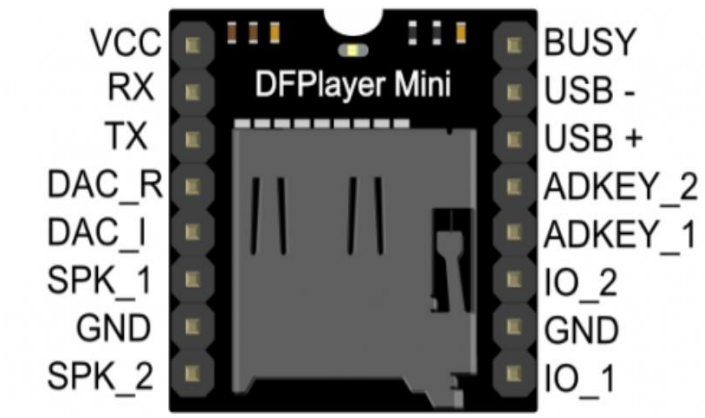



*Figure 38: DFPlayer Mini pin diagram.*

**b) Speaker**

Given the fact that the DFPlayer Mini module is able to drive up to 3 watt loudspeaker, we decided to incorporate in our project a speaker with an impedance of 8 Ω and power of 1 W. This speaker is small, lightweight, and simple in use and serves perfectly the purpose of our project.

*Figure 39: Mini Metal Speaker w/ Wires - 8 ohm 1W.*

### B) Voice control device

#### i. Voice recognition unit

The voice recognition unit is based on the Voice Recognition Module ELECHOUSE V3 (Figure 40) which is an affordable and easy to operate voice recognition module that can store up to 80 voice commands each with a duration of 1500ms and can be controlled using two different methods [79]:

- **Serial Port:** In this method the voice commands are not converted in text but are compared with an already recorded set of voices. This means that are no language barriers in using the module and thus sounds in any language can be used as commands. The module need to be trained before being able to recognize any command.
- **General Input Pins (GPIO)**: If the module is used using this method it has the capacity to deliver only 7 commands out of 80 at the same time. Initially the user need to select and load 7 commands in to the recognizer and the recognizer will send outputs to the respective GPIO pins if any of these voice commands get recognized.

Should be noted that recognition accuracy of the module is affected by the sensitivity of the microphone and the environmental noise.

*Figure 40: Voice recognition module with a microphone.*

### ii. Controlled unit

The voice recognition module enables the control through voice messages of various electrical appliances such as lights and the cooling system which in our prototype are represented by LEDs and a mini fan respectively (Figure 41). Regarding the fan, its control is accomplished by utilizing a driving circuit which consist of a transistor, a resistor and a diode and its powering circuit is enabled by a 9V battery in combination with a voltage regulator. More information about the working principles of the driving and powering circuit of the fan are provided in the next chapter.

a) b)

*Figure 41: a) LEDs, b) Fan.*

### iii. Power supply

The home assistance system is powered using a power bank of 10000mAh capacity (Figure 42). The power bank uses a lithium ion battery and it is equipped with a micro-USB input port and USB output port in which a USB cable can be attached to connect the power bank to any compatible device [**80**].

*Figure 42: Power bank.*

### 3.2.3. Software

Similarly to the mobility aid system the smart home assistance system is programmed in C/C++ language using the Arduino IDE software. For a better understanding the code of voice notifications and voice recognition device is analyzed separately.

### i. Voice notification device

```
#include "Arduino.h"
#include "SoftwareSerial.h"
#include "DFRobotDFPlayerMini.h"
SoftwareSerial mySoftwareSerial(10, 11);  // RX, TX
DFRobotDFPlayerMini myDFPlayer;
```

In the first lines our code involve the installation three libraries that are crucial for the operation of the voice notification device.

- **Arduino.h:** The Arduino library comes installed in in the Arduino IDE. **DFRobotDFPlayerMini.h:** Specially designed library that is published by DFRobot on GitHub and aims to simplify the use of the DFPlayer.
- **SoftwareSerial.h:** This library enables the Arduino to send commands to the DFPlayer min and similarly to Arduino.h to library is installed in the Arduino IDE. We can use the hardware serial pins (0 and 1) to enable the communication of Arduino with the DFPlayer min, however these pins are the same pins used by Arduino to communicate with the computer and may produce errors when uploading the code. In effort to tackle this issue the SoftwareSerial library uses software to replicate the serial communication on other digital pins of the Arduino. In our code (line 4) digital pins 10 and 11 are used for this purpose.

```
#define trigPin1 3
#define echoPin1 2
#define trigPin2 4
#define echoPin2 5
#define flame    6
const int temp=A0;
float vout;
float tempc;
long duration, distance, distance1, firstSensor, secondSensor;
```

Next, are defined the pins in which are connected the ultrasound sensors, the flame sensor and the temperature sensor. In contrast to other sensors the temperature sensor is connected to the analog pin A0 as it provides an output voltage linearly proportional to the Centigrade temperature. Moreover, in this section of the code are defined and some variables the purpose of which will be explained in the next paragraphs.

```
void setup()
{
   mySoftwareSerial.begin(9600);
   Serial.begin(115200);

  pinMode(trigPin1, OUTPUT);
```

```
  pinMode(echoPin1, INPUT);
  pinMode(trigPin2, OUTPUT);
  pinMode(echoPin2, INPUT);
  pinMode(flame, INPUT);
  pinMode(temp,INPUT);
  //pinMode(alarm, OUTPUT);
  Serial.println();
  Serial.println(F("DFRobot DFPlayer Mini Demo"));
  Serial.println(F("Initializing DFPlayer ... (May take 3~5 seconds)"));

  if (!myDFPlayer.begin(mySoftwareSerial)) {  //Use softwareSerial to communicate with mp3.
    Serial.println(F("Unable to begin:"));
    Serial.println(F("1.Please recheck the connection!"));
    Serial.println(F("2.Please insert the SD card!"));
    while(true);
  }
  Serial.println(F("DFPlayer Mini online."));

  myDFPlayer.volume(30);  //Set volume value. From 0 to 30

}
```

Initially, in the **setup** function of the code the baud rate for the serial communication between the Arduino and the PC is established at 9600bps and between the Arduino and the DFPlayer is is established at 115200bps. Next, using the pinMode function the mode of digital pins is declared. In addition, in the next lines of the code the possibility of having issues in the proper operation of DFPlayer is taken into account by the appearance of appropriate messages in the Serial Monitor in case of any issue. Lastly, using **myDFPlayer.volume** the volume of voice messages is set at maximum value.

```
void loop() {

  // read distance data from both sensors
  SonarSensor(trigPin1, echoPin1);
  SonarSensor1(trigPin2, echoPin2);
  firstSensor = distance;
  secondSensor = distance1;
  int fire=digitalRead(flame);
  vout=analogRead(temp); //Reading the value from sensor
  vout=(vout/1023)*5000;
  tempc=vout/10; // Storing value in Degree Celsius
  Serial.print("in DegreeC=");

  Serial.print("\t");
```

```
  Serial.print(tempc);

  Serial.println();

  delay(500); //Delay of 1 second for ease of viewing
    if (distance < 50 ) {
    myDFPlayer.play(1);
    delay(5000);
  } else if (distance1 < 50 ) {
    myDFPlayer.play(2);
    delay(5000);
  }
  else if ((fire==1)) {
    myDFPlayer.play(3);
    delay(5000);
  }
  else if (tempc>=35) {
    myDFPlayer.play(4);
    delay(5000);
  }
}

void SonarSensor(int trigPin,int echoPin)
{
  digitalWrite(trigPin, LOW);
  delayMicroseconds(2);
  digitalWrite(trigPin, HIGH);
  delayMicroseconds(10);
  digitalWrite(trigPin, LOW);
  duration = pulseIn(echoPin, HIGH);
  distance = duration * 0.034 / 2;
}

void SonarSensor1(int trigPin,int echoPin)
{
  digitalWrite(trigPin, LOW);
  delayMicroseconds(2);
  digitalWrite(trigPin, HIGH);
  delayMicroseconds(10);
  digitalWrite(trigPin, LOW);
  duration = pulseIn(echoPin, HIGH);
  distance1 = duration * 0.034 / 2;
}
```

In last section of the code we have the **void loop** function in which initially are called the functions regarding each of the ultrasound sensors involved in our prototype. These function are similar with those used in the mobility aid device and their role is to calculate the distance between the sensor and the blind person when enters each room. When the distance becomes less than 50cm each sensors triggers the activation of an appropriate voice message.

In addition, using the **analogRead** function the output voltage of the temperature sensor is obtained and using a mathematical formula is converted in degrees of Celsius. Next, the measured temperature is compared to a threshold and when it passes that threshold a voice massages its generated to inform the blind person.

Finally, regarding the flame sensor the “fire” variable is used to store the digital outputs from the flame sensor. The stored values are compared with the logical value “1” which indicates that flame has been detected. When the equality is validated the voice message about fire generated.

### ii. Voice control device

```
#include "VoiceRecognitionV3.h"
#include <SoftwareSerial.h>
VR myVR(12,13);    // 12:RX 13:TX
```

Similarly to the code of voice notification device the first lines of code involve the installation of important libraries for the smooth operation of the system. The first library is the VoiceRecognitionV3 which facilities the use of Voice Recognition Module V3. The second library is the SoftwareSerial which enables the Arduino to communicate with the Voice Recognition Module V3 using pin 12 and 13.

```
int ledbedroom = 7;
int fan = 8;
#define bedroomon     (0)
#define bedroomoff    (1)
#define fanon  (2)
#define fanoff (3)
```

Next, are defined the pins in which are connected the LEDs and the fan and also are defined variables in which are stored the voice commands.

```
void setup()
{
      myVR.begin(9600);
    Serial.begin(115200);
   pinMode(ledbedroom, OUTPUT);
  pinMode(fan, OUTPUT);
  // set both off by default
  digitalWrite(ledbedroom, LOW);
  digitalWrite(fan, LOW);
```

```
  Serial.println("Elechouse Voice Recognition V3 Module\r\nControl LED sample");
  if(myVR.clear() == 0){
    Serial.println("Recognizer cleared.");
  }else{
    Serial.println("Not find VoiceRecognitionModule.");
    Serial.println("Please check connection and restart Arduino.");
    while(1);
  }

  if(myVR.load((uint8_t) bedroomon) >= 0){
    Serial.println("onRecord loaded");
  }

  if(myVR.load((uint8_t) bedroomoff) >= 0){
    Serial.println("offRecord loaded");
  }
  if(myVR.load((uint8_t) fanon) >= 0){
    Serial.println("onRecord loaded");
  }

  if(myVR.load((uint8_t) fanoff) >= 0){
    Serial.println("offRecord loaded");
  }
}
```

Initially, in the **setup** function the baud rate for the serial communication between the Arduino and the PC is established at 9600bps and between the Arduino and the Voice Recognition Module is established at 115200bps. Next, digital pins in which are conceded the controlled units are declared as output pins and their initial status is set to be LOW, meaning that will be off when the device starts the operation. In addition, in the next lines of the code using the **myVR.load** function of VoiceRecognitionV3 library voice commands are loaded to the module.

```
void loop()
{
  int ret;
  ret = myVR.recognize(buf, 50);
  if(ret>0){
    switch(buf[1]){
      case bedroomon:
        digitalWrite(ledbedroom, HIGH);
        break;
      case bedroomoff:
        digitalWrite(ledbedroom, LOW);
        break;
      case fanon:
```

```
      digitalWrite(fan, HIGH);
      break;
    case  fanoff:
      digitalWrite(fan, LOW);
      break;
    default:
      Serial.println("Record function undefined");
      break;
   }
   /** voice recognized */
   printVR(buf);
  }
}
```

Finally, the **loop** function checks if the message that is announced by the user matches any of the loaded messages in the module. When there is a match the action that is associated with that message takes place.

# Chapter 4: Implementation and evaluation

This chapter details how the selected materials were initially tested, trained (in case that is required) and then incorporated in order to achieve the desired requirements for each proposed system. In addition the operation of the systems is explained and their effectiveness is evaluated using various testing methods.

## 4.1. Mobility aid system

### 4.1.1. Components testing

Initially, all the electronic components were tested in order to ensure that they work properly. More specifically, we placed the Arduino Nano on a breadboard and via a USB we connected it to a computer. Then we checked if the LED on pin 13 was blinking. The blinking of the LED indicates that the board works properly.

Next, the accuracy of the readings from the ultrasonic sensors was tested by placing each one of them separately on the breadboard and connecting them directly to the Arduino Nano using male-to-male jumper wires. A simple sketch (Figure 43) was upload on the Arduino and the detected distances were displayed on the Serial Monitor. During the test each sensor was placed on one end of the table and on the other end was placed an object**.** The distance of the object from the sensor was constantly changing and a meter was used to measure it (Figure 44.a). The results from the test indicated that the sensors provide accurate readings as the distances that were displayed on the Serial Monitor (Figure 44.b) were similar with those that we measured with the meter.

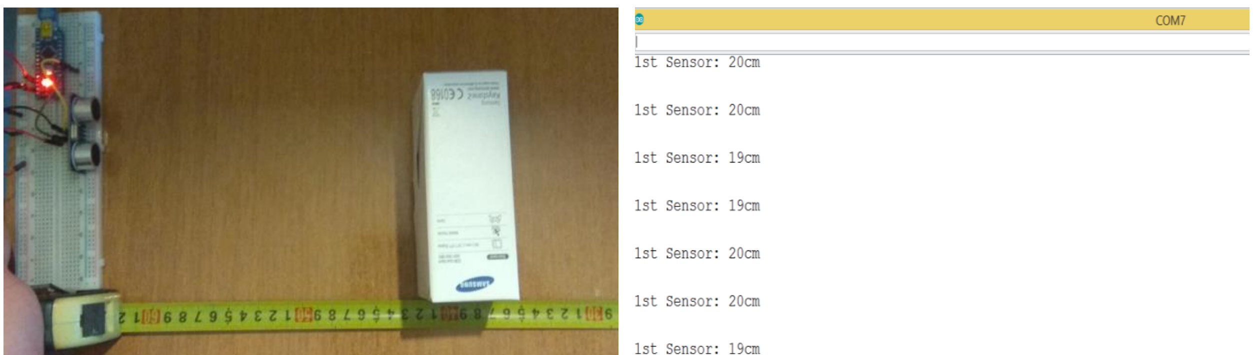
```
const int trigPin1=3;
const int echoPin1=4;
const int Buzzer= 2;
int distance1;
long duration1;
void setup() {
  pinMode(trigPin1, OUTPUT); // Set the tringPin1  as output
  pinMode(echoPin1, INPUT); // Set the EchoPin1  as input
  pinMode(Buzzer, OUTPUT); // Set the Buzzer  as output
  Serial.begin (9600); // Start the serial communication
}

void firstsensor(){ // This function is for first sensor.
  // Clears the trigPin1
  digitalWrite(trigPin1, LOW);
  delayMicroseconds(2);
  digitalWrite (trigPin1, HIGH);
  delayMicroseconds (10);
  digitalWrite (trigPin1, LOW);
  duration1 = pulseIn (echoPin1, HIGH);
```

```
  distance1 = duration1 * 0.034 / 2;
 digitalWrite(Buzzer, LOW);
     Serial.print("1st Sensor: ");
     Serial.print(distance1);
     Serial.print("cm    ");

void loop() {
Serial.println("\n");
firstsensor();
delay(100);
}
```

*Figure 43:* US sensor accuracy testing sketch.




a) b)

*Figure 44: a) US sensor accuracy testing, b) Serial Monitor results.*

Lastly, the working of the buzzer and vibrator motor was tested by simply connecting the positive terminal of each sensor to 5volts of Arduino and the negative terminal to GND pin and checking if are activated. Depending on the current and voltage that they can tolerate a resistor was placed between each actuator and the power supply in order to ensure that are not damaged.

#### 4.1.2. Circuit design

Once the testing of selected electrical components is completed and we are sure that they work properly, the wiring of all components is sketched (Figure 45) in order to keep track all the connections and enable and an easier and more organized assembly. The wiring of electronic components was drawn using the latest version of Fritzing software.

Fritzing is an open-source Electronic Design Automation software that aims at making electronics more accessible to anyone. It offers a virtual breadboard where the virtual components can be placed and wired and also it can turn circuits into PCB (Printed Circuit Board) layouts ready for production. More information regarding Fritzing can be found in [**81**].

Should be noted that in the Fritizing schematic all the components are placed on a regular breadboard while in the actual prototype the placement of the components is done on two Mini-breadboards due to the fact that the Mini-breadboards provided by Fritzing are smaller in size than the Arduino Nano which makes them totally inappropriate for sketching components wiring.

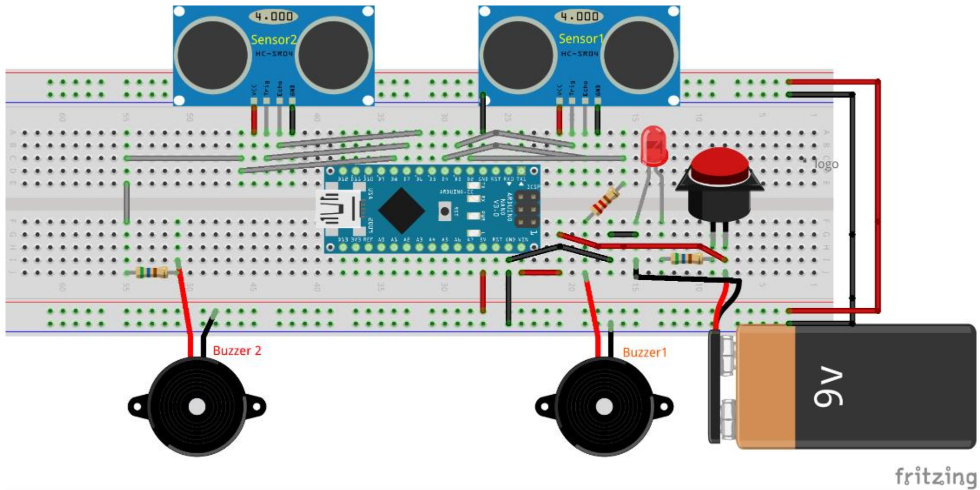



*Figure 45: Fritzing schematic of mobility aid system.*

### 4.1.3. System assembly

Based on the Fritzing schematic we start to assemble all the components of the mobility aid device outlined in the previous chapter. In order to maintain a small and lightweight design we decided to place the components on two mini-breadboards which we glued together (Figure 46). In addition to being small and lightweight the two mini-breadboards make our system more flexible as the components are not soldered and so can be easily removed in case of damages or changes in the design. Despite the fact that the PCB is the ideal choice when creating electronic product, in our application we decided to not continue with its contraction as the Mini-breadboard is a much more cost-effective and time-efficient option and help us to ensure that all the objectives outlined in Section 1.3 are met successfully.

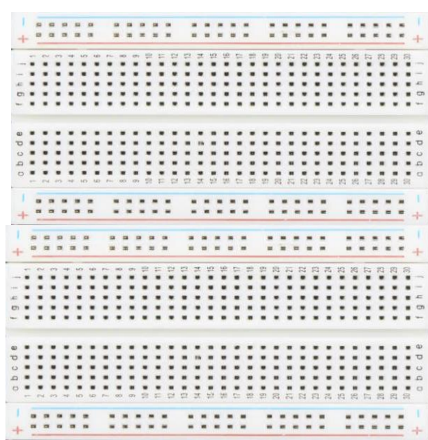


*Figure 46: Two mini-breadboards which we glued together.*

As can be noticed from the figures bellow (Figure 47) in the center of one of the breadboards is placed the Arduino Nano which acts as the control unit and all components are connected to it using small cable wires which make our system more organized. To power the Arduino Nano a 9V battery is integrated and a push button is used to activate the whole system. Once the button is pushed the current flows from the battery to the Arduino board which starts to execute the uploaded code that controls the connected sensors and actuators.

Two HC-SR04 ultrasonic sensors are used for detection of obstacles. The integration of two sensors instead of one makes our device more flexible and reliable as the S1 sensor is used for detection of obstacles that are in front of the user from the leg to the chest region whereas the S2 sensor serves for the detection of objects that are encounter around the head region and due to this fact the S2 sensor in the prototype is placed above the S1 sensor at approximately 45$^o$ degrees angle which is a different position than that depicted in the schematic. Depending on the sensor that makes the detection of obstacles the user is notified by either a beeping sound of low intensity or a beeping sound of high intensity which are generated from the piezoelectric buzzers. The intensity sounds is decided to reflect the severity of the injury that can be caused due to collision and thus the high intensity sounds are generated to indicate that a collision at head level is about to happen were injuries can be proven much more serious than on other body parts. The differences in the intensity of produced sounds were achieved by choosing protective resistors of different value for each buzzer. The lower the value of the resistor the higher the intensity of the beeping sound.

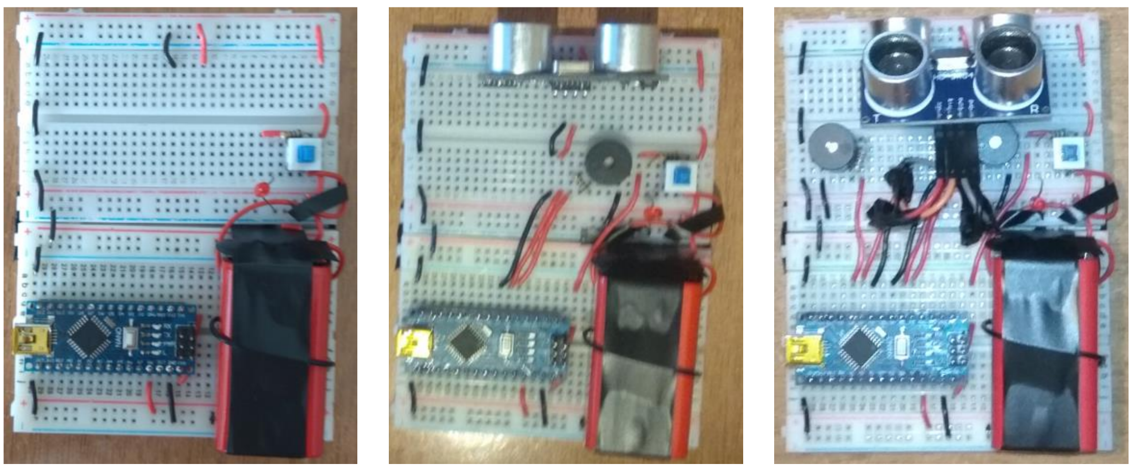
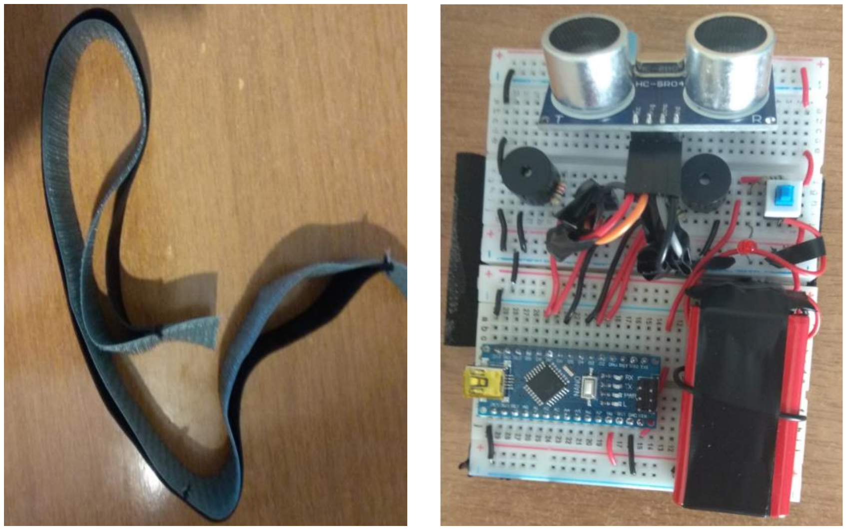


*Figure 47: Photos from various steps of the assembly process.*

Last but not least, some elastic and stickers (Figure 48.a) are used to make mobility aid device wearable in the form of wristband or glove. The mini-breadboards were glued on elastic and stickers (Figure 49.a) so can easily be worn on the right or left hand. (Figure 48.b). Placement on the wrist or hand (Figure 49.b) makes the device more efficient as the least amount of sensors is used to achieve the best possible detection capability. Furthermore, the device becomes less obstructive as users can constantly scan the environment by directing their hands towards the direction they wish to check for obstacles without interrupting their daily activities and movements.



a) b)

*Figure 48: a) Elastic and stickers, b) Mini-breadboards glued on elastic and stickers.*

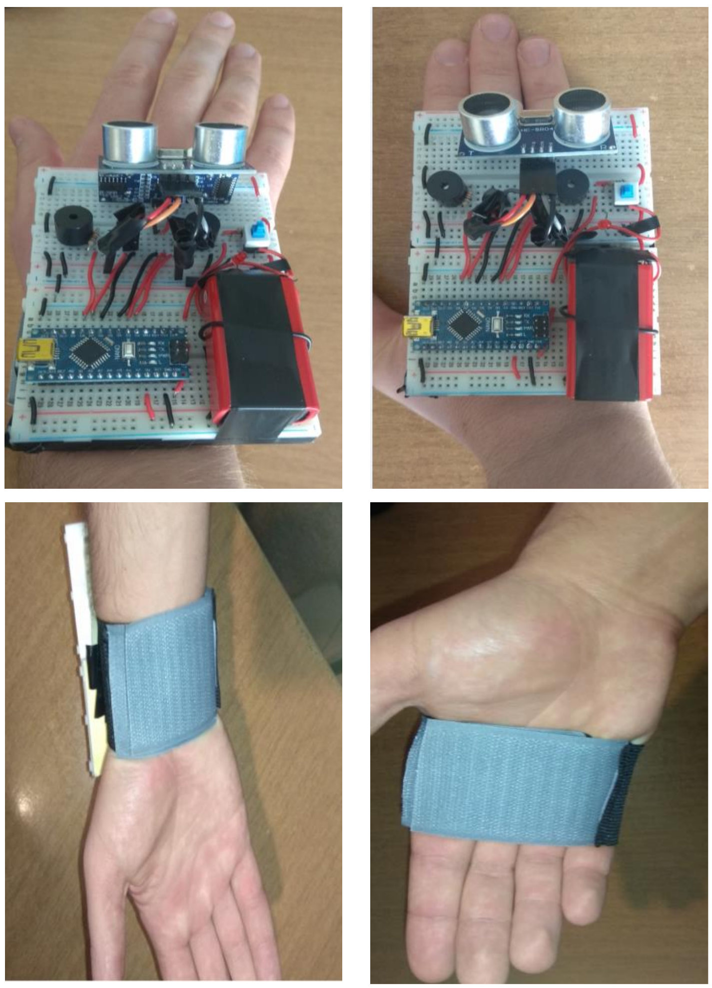


*Figure 49: Final device placed on the wrist and on the hand.*

### 4.1.4. Testing and evaluation

Due to the lack of well-established evaluation methods for the performance of mobility aid devices we decided that is important to test the effectiveness of our device in indoor environments. The experiment featured four sighted participants (4 male aged 22-28) and most were university students. All the participants were recruited by word of mouth and verbal consent was obtained from each participant prior to entering the experimental process. At the beginning of each experiment participants received a 10-minutes training which involved a basic explanation of how the device works and how to use it. As the device is wearable in form of wristband or glove the participants were asked to choose the hand in which are comfortable to wear the device. During the experiments, participants were blindfolded using a sleeping mask to simulate lack of vision (Figure 50) and were asked to perform the experiment two times and each time the position between participant and obstacles differed slightly.


*Figure 50: Testing of the mobility aid system.*

The experiment was designed to include some of the most commonly encountered objects within the home such as tables, chairs, walls and garbage bin. The objects were arranged in semi random position and were put in different heights to represent chest-level, waist-level and foot-level obstacles. The whole course was approximately 5m long and 2m wide.

Once the experiment was completed the performance of the device was evaluated based on a questionnaire filled by each participant. The questionnaire was designed for users to provide feedback so future improvements can be made on the prototype. The questionnaire that can be seen in table below included 6 different parameters regarding their experience using the device. Each parameter was to be scored from 1 to 5 points, with 1 point representing the lowest possible score. The obtained results are presented in Table 3 and Figure 51.

**Table 3: Questionnaire's results**

| Parameters | Participant 1 | Participant 2 | Participant 3 | Participant 4 | Average score |
|---|---|---|---|---|---|
| Difficulty in use | 3 | 4 | 4 | 4 | 3.75 |
| Weight and dimensions | 4 | 3 | 4 | 4 | 3.75 |
| Comfort | 3 | 3 | 5 | 3 | 3.5 |
| Confidence level using the device | 3 | 2 | 3 | 3 | 2.75 |
| Accuracy in detecting obstacles | 3 | 5 | 5 | 4 | 4.25 |
| Overall impression | 3 | 3 | 3 | 3 | 3 |

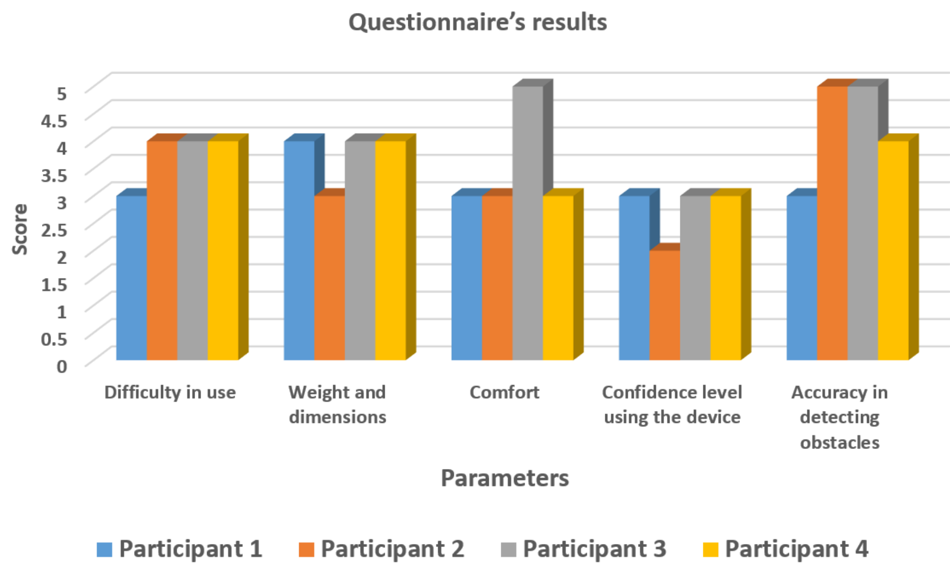



*Figure 51: Graphical representation of obtained results.*

From the obtained results and the gathered feedback becomes evident that the participants are satisfied with the performance of the system as in the majority of parameters the average score is above 3 and all the participants have validated the fact that the system is lightweight, intuitive in use and less obstructive. A common limitation pointed out by participants is the fact that the device faces difficulties in detection of obstacles that are near the ground and small in size.

## 4.2. Home assistance system

Initially, in this sections the preparation and training of Elechouse V3 Voice Recognition module is presented. Next, is presented the preparation of mp3 file of the DFpalyer module and a detailed analyses of the driving and powering circuit of the fan. Lastly, the fritzing schematic of the home assistance system is designed and the assembly process is descripted.

### 4.2.1. Preparation and training of Elechouse V3 module

Before starting the training, in order to facilitated the connection of the module with the Arduino Nano we use a soldering iron (Figure 52) to solder male headers over the bottom side of the module where are situated the GND, VCC, RXD, and TXD. After the soldering process is completed, using a multimeter we check if the pins are soldered correctly. Next, by bearing in mind the following instruction we use male to female type jumper wires to interface the module with the Arduino.

- Connect the ground of the Voice recognition module with the Arduino's Ground
- Connect the VCC of the voice recognition module with the Arduino's 5v.
- Connect the RXD of the voice recognition module with pin 13 of the Arduino.
- Connect the TXD Pin of the voice recognition module with pin 12 of the Arduino.

Finally, before moving on to the training part, we plug the microphone to the module and connect the Arduino to a PC using a USB cable. After the connection is established we are ready to train our module.

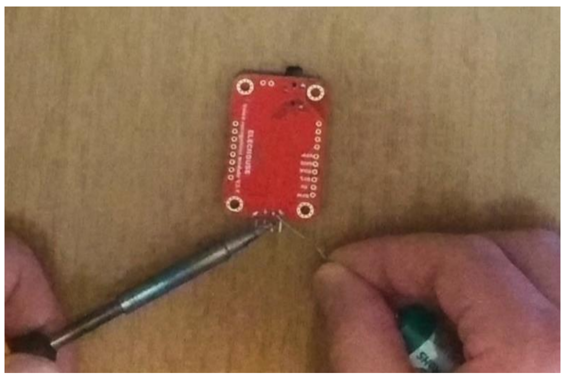


*Figure 52: Soldering*

First of all, we upload the "vr_sample_train" sketch to Arduino. Moreover, we open the Serial Monitor and set the baud rate to 115200 and select the option "Newline". If everything is fine the following menu (Figure 53) will appear on the Serial Monitor.

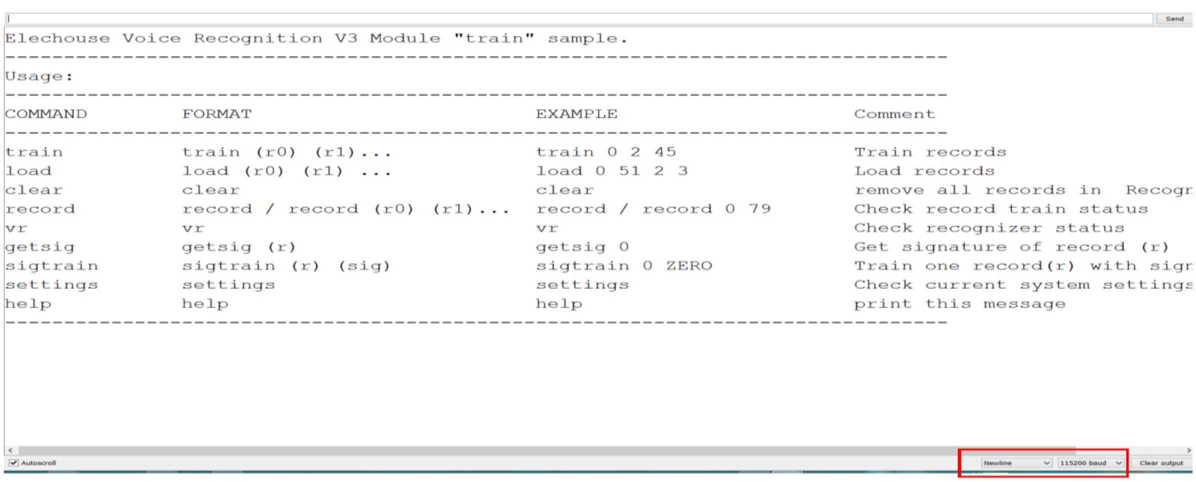



*Figure 53: Initial menu before training.*

Next, using the “sigtrain” command we start to train the module. The “sigtrain” stores a voice command into specific address and it assigns on each command a specific signature. The syntax of the command goes like this: sigtrain + address + signature. For example, sigtrain 0 on, sigtrain 20 off. Once the command is entered a message that says “speak now” appears on the Serial Monitor. At that moment we speak the command to the microphone clear and loud. If the command is clear enough another message will appear asking us to speak again. We repeat the command again and in case that matches the previous the message “success” appears (Figure 54). If the environmental noise is too loud we will be asked to repeat the command again until is clear enough. Once the command is successful matched, we repeat the same process to input other voice command into module.

```
-------------------------------------------------------------------------------
sigtrain 0 bedroomon
-------------------------------------------------------------------------------
Record: 0       Speak now
Record: 0       Speak again
Record: 0       Cann't matched
Record: 0       Speak now
Record: 0       Speak again
Record: 0       Success
Success: 1
Record 0        Trained
SIG: bedroomon
-------------------------------------------------------------------------------
```

*Figure 54: Training using “sigtrain” command.*

Finally, using the “load” command we load all the commands into the module (Figure 55).

```
load 0 1 2 3
-------------------------------------------------------------------------------
Load success: 4
Record 0        Loaded
Record 1        Loaded
Record 2        Loaded
Record 3        Loaded
-------------------------------------------------------------------------------
VR Index        Group   RecordNum       Signature
0               NONE    0               bedroomon

VR Index        Group   RecordNum       Signature
1               NONE    1               bedroomoff

VR Index        Group   RecordNum       Signature
2               NONE    2               fanon

VR Index        Group   RecordNum       Signature
3               NONE    3               fanoff
```

*Figure 55: Uploading commands.*

Given the fact that in our home assistance system we want to turn on and off the lights in the bedroom and the fan (cooling system), we need to use four different voice command. After trying various commands and checking the response of the module we come to the conclusion that the best performance is ensured using monosyllable Greek words, thus it was decided that the use of numbers from one to four will be the most suitable choice. Below are presented the commands that are utilized and the action that corresponds with each of them.

- ”Ένα”→ Turn on the lights in the bedroom.
- ”Δυο”→ Turn off the lights in the bedroom.
- ”Τρία”→ Turn on the fan.
- ”Τέσσερα”→ Turn off the fan.

### 1.2.2. Mp3 files preparation

Mp3 files that are stored in micro SD card of DFPlayer mini module are created with the help of a smartphone and “Natural Reader” which an online text to speech converter [82]. Each of the messages that is presented below is initially written in English language on the Natural Reader and then using a smartphone is recorded. The voice messages (Figure 56) are stored in form of mp3 file and named based on a 4 digit number. After that mp3 files are added into a folder that is named using 2 digits (01) and finally are transferred into a micro SD card that later will be inserted in the DFPlayer module.

- 0001.mp3→ You are in the bedroom.
- 0002.mp3→ You are in the living room.
- 0003.mp3→ Be careful fire evacuate the home immediately.
- 0004.mp3→ The temperature is too high activate the fan.


*Figure 56: Mp3 files.*

### 1.2.3. Circuit design

#### i. Fan driving circuit

Given the fact that the digital pins of Arduino Nano can provide 40mA and the fan requires 0.138A to operate we decided to design a circuit which will manage to drive the fan. The circuit (Figure 57) consists of a BC548B transistor, a 820ohm resistor and a 2N2222 diode. The BC548B transistor is a NPN Bipolar Junction Transistor (BJT) that is used to switch on the fan and it can handle currents up to 200mA in the collector. The 2N2222 diode is a Schottky diode which is placed in parallel with the fan in order to prevent the transistor for being destroyed by inductive kick-back. Inductive kick-back occurs when the transistor is turned off and the current from the fan that is an inductive load is uncharged on the collector of the transistor. The diode acts as a barrier to these current and feeds it back into to the fan, preventing the damage of the transistor. Finally, a resistor is connected in series with the base of the transistor to limit the base current. The value of the resistor is calculated using the following equation.

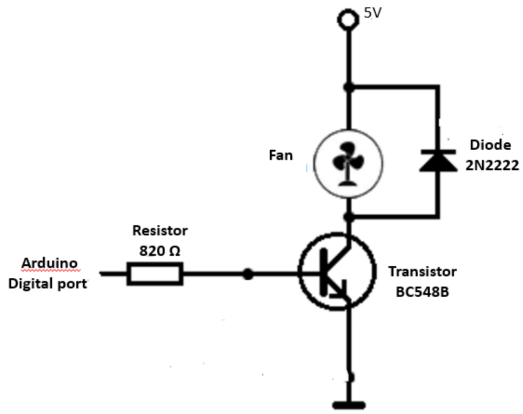



*Figure 57: Fan driving circuit.*

$$R = \frac{Vs - 0.7V}{10 * \frac{Ifan}{\beta}} \; Eq. 2$$

- Vs is the supply voltage which in our case is 5V
- Ifan is the current that the fan draws which in our case is 0.138A
- β is the current gain of the transistor which in our case is 200
- The factor 10 is to have enough margin as to make sure that the transistor will never work in the linear region.

Based on the equation and the values of parameters the resistor was calculated to be 623Ω. In order to ensure that base current is limited we decided to choose a resistor of a slightly larger value. From the resistors available in the market the 820Ω was considered the most suitable.

**ii. Fan powering circuit**

During the testing of the home assistance system was noticed that when the fan was activated the value of the temperatures provided by the LM35 was increasing significantly thus in order to tackle this issue was decide to power the fan not from the Arduino but from an external 9V battery. Given the fact that the fan requires only 5V to work a voltage regulator was incorporated in the circuit to converter the input 9V to 5V. After investigating the technical specifications of various voltage regulator was decided that the LM7805 linear voltage regulator is the most appropriate choice as it can provide a constant 5V and it requires only two capacitors 330nF and 100nF to work properly (Figure 58).

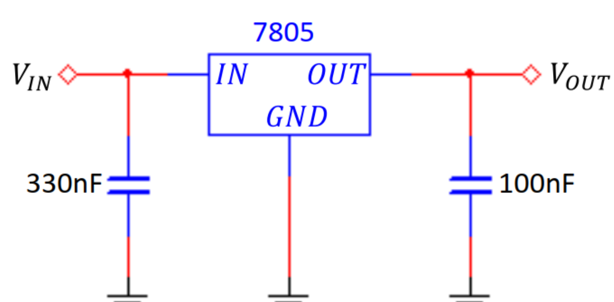



*Figure 58: Powering circuit.*

#### iii. Overall wiring diagram

Similarly to the mobility aid system the wiring of all components (Figure 59) of the home assistance system is sketched using Fritzing software.

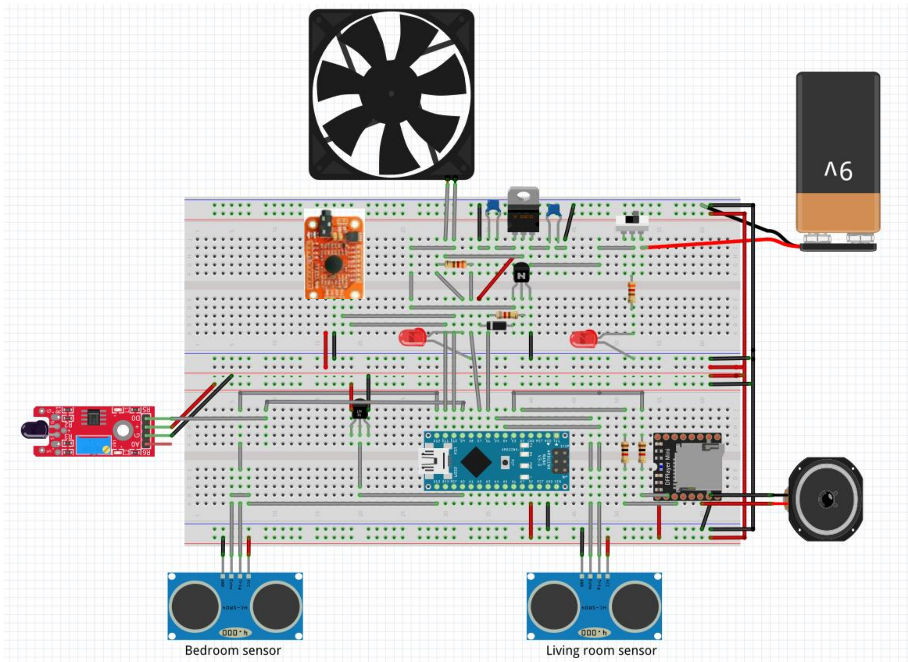



*Figure 59: Fritzing schematic of home assistance system.*

### 1.2.4. System assembly

By bearing in mind the wiring of components that is depicted in the Fritzing schematic we start to assemble all the components that are presented in the section 3.2.2. All the components are connected with each other and the Arduino Nano using small cable wires that make our system more organized and are placed on two breadboards that are glued together. To power our prototype we connect the power bank via a USB cable to the Arduino Nano.

First of all, regarding the voice notification device (Figure 60) two HC-SR04 ultrasonic sensors are used to detect the blind person's presence in bedroom and living room. These sensors will be placed in the entrance of each room and when the blind person enters the room an appropriate voice message will be generated by the speaker to notify the blind in which room has entered. In order to minimize the noise that may accompany the voice message a 1K resistor is attached to RX and TX pins of the DFPlayer module. Furthermore, the LM35 temperature sensor is attached to the A0 analog pin of Arduino to monitor the temperature in the home and the KY-026 flame sensor is attached to digital pin 6 to check the presence of fire The trimmer of the flame sensor is carefully adjusted in order the sensors to be sensitive only to the radiation generated by the fire and not the environmental or artificial light.

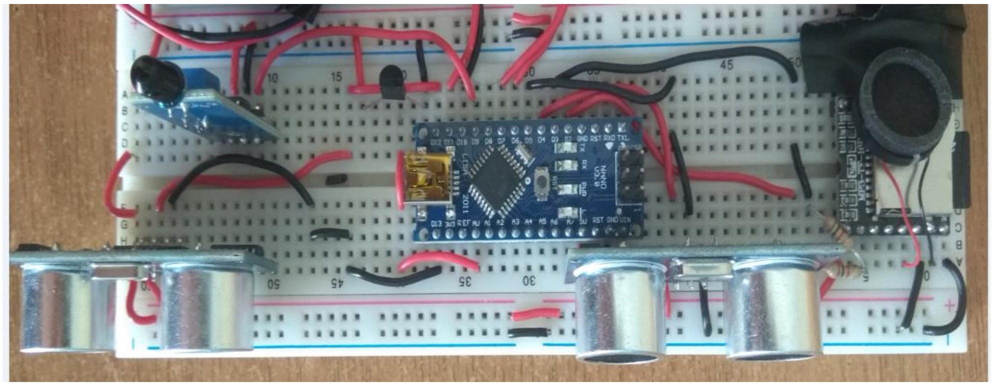


*Figure 60: Wiring of voice notification device.*

Secondly, regarding the voice control device (Figure 61) the trained Elechouse V3 module is interfaced with the Arduino Nano by connecting the TX and RX to pins 12 and 13 pins of Arduino. Next, a red LED that represents the lights in the bedroom is attached through a 330Ω resistor to the pin 7 of the Arduino. The role of the resistor is to limit the current follow to the LED. Final, the 5V fan and its driving and powering circuit are placed on the breadboard. By sending voice commands the blind person can activate the lights in the bedroom and the fan when receives message that the temperature is too high. The final result of home assistance system is depicted in Figure 62.

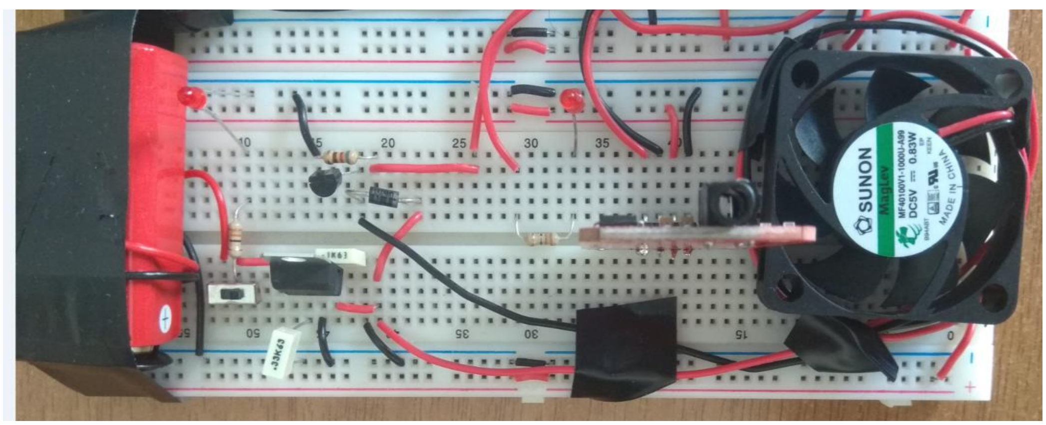


*Figure 61: Wiring of voice control device.*

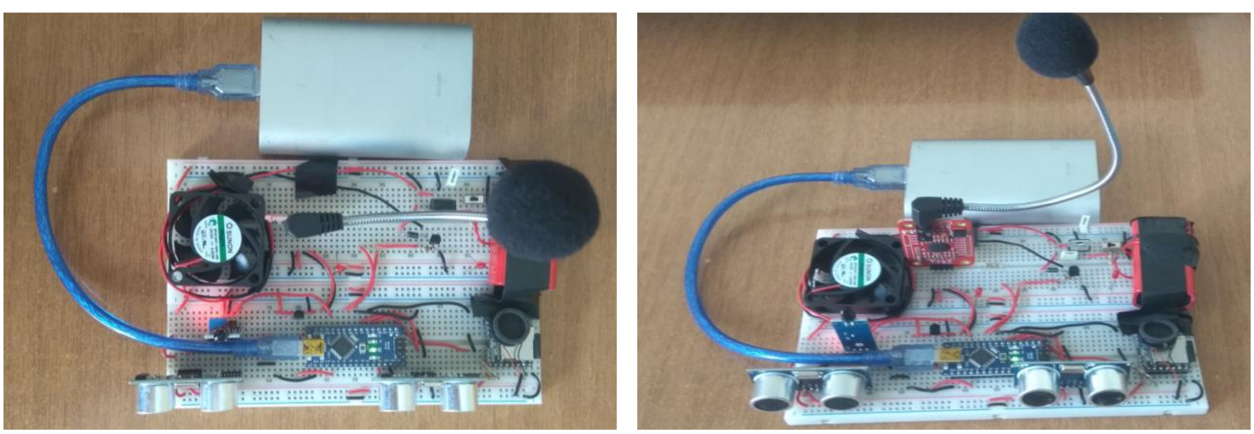


*Figure 62: Final result.*

### 1.2.5. Testing and evaluation

Regarding the testing of home assistance system we tried to test if the utilized sensors and actuators response effectively. More specifically, we placed an object in front of each ultrasound sensors and checked if the appropriate voice message was generated. Next, in order to raise the temperature we placed our hand on the temperature sensor and waited to see if the voice message about the passing of temperature limit is activated. In addition, turning on a lighter in front the flame sensor we checked if is generated the message about detection of fire. Finally, regarding the voice control device we tested if the voice recognition unit can recognize the received voice commands, perform the actions associated with each command and also we tried to establish the maximum distance from the microphone in which the voice recognition module can successfully identify the received commands.

From the obtained results becomes evident that whole system has a satisfactory performance as each sensor of detection unit has a fast response and the speaker generates the corresponding voice messages fast and correctly. Regarding, the voice control device, the LED and the fan are easily controlled using voice commands and the maximum distance from the microphone in which is attained a successful recognition of voice messages is about 1,5 meter. As the only limitation we can point out the fact that in noisy environment the voice recognition module struggles to recognize the voice commands and the maximum distance drops significantly.

# Chapter 5: Conclusions and future work

In this section are drawn the final conclusion regarding our thesis with emphasis on the functionality of proposed systems and their limitations. Furthermore, based on the gathered feedback from the participants involved in the experiment and our future aspirations for the two assistive devices, future improvements are proposed.

## 2.1. Conclusions

Statistical evidence indicate that visual impairment remains one of the most challenging health issues of 21st century with devastating impact on the quality of life of the affected individuals.

Over the last decades, thanks to accelerating developments in fields of engineering combined with the advances in understanding of human physiology and anatomy various devices that focus on areas such as information access, mobility aid and smart cities are designed to facilitate the living of visually impaired. Regarding the available mobility aid and smart city devices, despite the enormous efforts is evident that there is plenty of room for improvements as usually those devices are bulky, complex in operation, expensive and in some cases fail to attain the initial claims by manufactures and researchers, leading to disappointment and frustration among the visually impaired people. In an effort to tackle these issues we decided to develop two assistive devices that are tailored to the needs of visually impaired people.

The first device is a mobility aid system that aims at empowering visually impaired people to navigate independently in indoor or outdoor environments. In order to be user-friendly and less obstructive the system is designed to be wearable in form wrist or hand mounted glove. The system has the ability to detect obstacles at various heights as it is equipped with two ultrasound sensors. The first sensor is responsible for the detection of obstacles that a situated from ground to chest level and the second is responsible for detection of obstacles that are at head height. Depending on the sensor that makes the detection the user is notified by beeping sounds of low or high intensity. The intensity sounds is decided to reflect the severity of the injury that can be caused due to collision and thus the high intensity sounds are generated to indicate that a collision at head level is about to happen were injuries can be proven much more serious than on other body parts.

The second device is a home assistance system that tries to enhance the quality of life of visually impaired individuals in their homes. In order to achieve this it utilizes a voice recognition module that enables a remote control through voice commands of lights, cooling system or any household appliance. In addition, this systems is able to notify the user through voice messages about the detection of fire, the overcoming of specific threshold in temperature and which room has entered.

An indoor experimental scenario which featured 4 male sighted participants was used to evaluate the performance of mobility aid system. During the experiment participants were blindfolded using a slipping mask and were tasked to walk a course that contained some of the most commonly encountered objects within the home such as tables, chairs, walls, garbage bin etc. The evaluation was based on a questionnaire that included 6 different parameters regarding their experience using the device which were scored from 1 to 5 points, with 1 point representing the lowest possible score.

Based on the obtained results we conclude that the proposed system has successful attained the initially set objects as the average score in the majority of parameters is above 3. Furthermore, based on the collected feedback all the participants appreciated the fact that the device is lightweight, does not prevent the use of the hand for other tasks and it is intuitive in use as the learning curve is measured in less than ten minutes which is incomparable to the time required to learn Braille. However, some participants pointed out the fact the system has some shortcomings associate mainly with the fact that it struggles to detected objects that are near the ground and small in size. Moreover, another major drawback of the mobility aid system is that was not tested in outdoor environment due to lack of access to a place that can ensure a safe performance of the experiment.

Finally, regarding the testing of home assistance system was observed that the whole system has a satisfactory performance as the each sensor of detection unit has a fast response and the voice messages are generated correctly. Furthermore, the LED and the fan are easily controlled using voice commands and the maximum distance from the microphone in which is attained a successful recognition of voice messages is about 1,5 meters. As the only limitation we can point out the fact that in noisy environment the voice recognition module struggle to recognize the voice commands.

## 2.2. Future work

### 5.2.1. Mobility aid system

**i.** First, we plan to advance with the construction of PCB for our system and the addition of a protective cover.

**ii.** Second, we will replace the 9V battery with a rechargeable and lighter one in order the whole system to become less bulky. Next, a solar panel can be added to remove the anxiety of charging.

**iii.** Third, we will try to add in our system a fall detection and a location tracking feature that will lavage the potential of loT technologies. More specifically, we will utilize in our design a GSM/GPRS/GSPS module that will help relatives or caregivers to track the location of visually impaired people. In addition, possibility of fall will be taken in consideration by incorporating an ESP8266 module in combination with an accelerometer and a gyroscope which will be able detect if the blind has fallen and give notifications via email using IoT app such as Blynk.

**iv.** Fourth, in long-term we plan to miniaturize the whole system and upgrade the sensing module. A right step in this direction will be the replacement of Arduino Nano by Arduino Mini and the replacement of HC-SR04 ultrasonic sensors with smaller ones that have a narrow beam of detection which can provide a more accurate location of obstacles.

**v.** The last suggested improvement does not concern the hardware or software aspects of the system but focuses on the evaluation process. Our task here will be threefold: First, we will try to verify the effectiveness of the device in indoor and outdoor environment. Second, we will create a more sophisticated testing method that will be able to examine more thoroughly the functionality of device and highlight all the potential weaknesses and strengths. Third, we will include in the experiments visually impaired people and we will increase the overall number of participants in order to gather more feedback which can be proven extremely valuable for further enhancement of the system.

#### 5.2.2. Home assistance system

**i.** First, similarly to the mobility aid system we plan to advance with the PCB construction, addition of protective cover and miniaturization of whole system.

**ii.** Second, thinking further about the possible enhancement of the system, the addition of more features seems to be a step in the right direction. For instance, the introduction of a system consisting of smart locks and motors that will be controlled by voice commands will prove to be really helpful for the remote opening and closing of doors and windows inside the house.

# References

[1] Radhika, R.; Payal, G.P.; Rakshitha, S.; Rampur, S. Smart stick for the blind a complete solution to reach the destination. Int. J. Mod. Treat. Eng. Res., 3, 659–662, 2016.

[2] Manduchi, R., & Kurniawan, S. Mobility-related accidents experienced by people with visual impairment. Insight Research and Practice in Visual Impairment and Blindness, 4, 1–11., 2011.

[3] P. Sharma and S.L. Shimi. Design and development of virtual eye for the blind, International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering, vol. 3, no.3, pp. 26-33, 2015.

[4] Bor-Shing Lin, Cheng-Che Lee, Pei-Ying Chiang: Simple Smartphone-Based Guiding System for Visually Impaired People. Sensors 17(6): 1371 (2017)

[5] Velázquez, R. (2010) "Wearable assistive devices for the blind," in Wearable and Autonomous Biomedical Devices and Systems for Smart Environment. Lecture Notes in Electrical Engineering, Vol. 75, eds A. Lay-Ekuakille and S. C. Mukhopadhyay (Berlin; Heidelberg: Springer)

[6] World Health Organization. Visual Impairment and Blindness. Available online: https://www.who.int/news-room/fact-sheets/detail/blindness-and-visual-impairment (Accessed on 26 April 2019).

[7] Pascolini, D. and Mariotti, S.P.M. Global Estimates of Visual Impairment 2010. British Journal of Ophthalmology, 96, 614-618, 2012.

[8] Hersh, M. A., & Johnson, M. A. (2008). Assistive technology for visually impaired and blind people. London: Springer-Verlag.

[9] V. Levesque, "Blindness, technology and haptics," ´ Center for Intelligent Machines, 2005.

[10] Γαλιατσάτος, Α., 2015. Βασικές αρχές οδοντικής αισθητικής- χρώμα και χαρακτηριστικά: Οφθαλμος - φυσιολογια της ορασης [ηλεκτρ. βιβλ.] Αθήνα:Σύνδεσμος Ελληνικών Ακαδημαϊκών Βιβλιοθηκών. Διαθέσιμο στο: http://hdl.handle.net/11419/980

[11] Yiallouros M. Anatomy and function of the eye, Last modification: 2016/11/21. Available online:https://www.kinderkrebsinfo.de/diseases/solid_tumours/pohretino_patinfo120120611/the_eye/index_eng.html (Accessed on 28 July 2019).

[12]Fox, Stuart Ira. Human Physiology. Ninth ed. ISBN 0-07-111584-6. New York: McGraHill, 2006.

[13] Ramamurthy M. and Lakshminarayanan V. Human Vision and Perception. (2015) Handbook of advanced lighting technology, Springe

[14] Mader S. Understanding Human Anatomy & Physiology, Fifth Edition McGraw−Hill, 2004.

[15] Huff T., and Tadi P. Neuroanatomy, Visual Cortex 15(1): 58-61 (2015). Available online: https://www.ncbi.nlm.nih.gov/books/NBK482504/ (Accessed on 28 July 2019).

[16] Kaiser PK. Prospective evaluation of visual acuity assessment: a comparison of snellen versus etdrs charts in clinical practice (An AOS thesis). Trans Am Ophthalmol Soc 2009; 107: 311-324.

[17]Teutsch M. Steven, mccoy A. Margaret, Woodbury R. B., and Welp A. Making eye health a population health imperative vision for tomorrow, The national academies press 500 fifth street, nw washington, dc 2001.

[18] World Health Organization. What is a refractive error? Available online: https://www.who.int/features/qa/45/en/ (Accessed on 26 April 2019).

[19] World Health Organization Vision 2020 the right to sight. Global initiative for the elimination of Avoidable blindness Action plan 2006–2011.

[20] Duh EJ, Sun JK, Stitt AW. Diabetic retinopathy: current understanding, mechanisms, and treatment strategies. JCI insight [Internet]. 2017 Jul 20; 2 (14).

[21] World Health Organization. What is trachoma? https://www.who.int/trachoma/disease/en/ (Accessed on 26 April 2019).

[22] Dohlman TH, Yin J, Dana R. Methods for Assessing Corneal Opacity. Semin Ophthalmol. 2019; 34(4):205-210.

[23] Kupers, R. and Ptito, M. Compensatory plasticity and cross-modal reorganization following early visual deprivation. Neuroscience and Biobehavioral Reviews 41 (2014) 36–52.

[24] Voss, P., Collignon, O., Lassonde, M., and Lepore, F. (2010). Adaptation to sensory loss. Wiley Intdiscip. Rev. Cogn. Sci. 1, 308–328.

[25] Heffner RS, Heffner HE. Hearing and sound localization in blind mole rats (Spalax ehrenbergi). Hearing Research 1992, 62:206–216.

[26] Withington-Wray DJ, Binns KE, Keating MJ. The maturation of the superior collicular map of auditory space in the guinea pig is disrupted by developmental visual deprivation. Eur J Neurosci 1990, 2:682–692.

[27] Jones B. Spatial perception in the blind. Br J Psychol. 1975, 66:461–472.

[28] Moos A, Trouvain J: Comprehension of ultra-fast speech – blind vs. "normally hearing" persons. In Proceedings of the 16th International Congress of Phonetic Sciences Volume 1. Edited by Trouvain J, Barry WJ. Saarbrücken: University of Saarbrücken; 2007:677–680.

[29] Hertrich I, Dietrich S, Moos A, Trouvain J, Ackermann H: Enhanced speech perception capabilities in a blind listener are associated with activation of fusiform gyrus and primary visual cortex. Neurocase 2009, 15:163–170.

[30] Dietrich S, Hertrich I, Ackermann H. Ultra-fast speech comprehension in blind subjects engages primary visual cortex, fusiform gyrus, and pulvinar–a functional magnetic resonance imaging (fMRI) study. BMC Neurosci. 2013; 14: 74.

[31] Hertrich I, Dietrich S, Ackermann H. How can audiovisual pathways enhance the temporal resolution of time-compressed speech in blind subjects? Front in Psychol. 2013.

[32] Dietrich S, Hertrich I, Ackermann H. Training of ultra-fast speech comprehension induces functional reorganization of the central-visual system in late-blind humans. Front Hum Neurosci. 2013; 7: 701.

[33] Cattaneo Z. and Vecchi T. (2011) Blind Vision Cambridge, MA: MIT Press.

[34] Wong, M., Gnanakumaran, V., Goldreich, D., 2011. Tactile spatial acuity enhancement in blindness: evidence for experience-dependent mechanisms. Journal of Neuroscience 31, 7028–7037.

[35] Goldreich, D., Kanics, I.M., 2003. Tactile acuity is enhanced in blindness. Journal ofNeuroscience 23, 3439–3445.

[36] Voss, P., Tabry, V., and Zatorre, R.J. (2015). Trade-offinthesoundlocalization abilities of early blind individuals between the horizontal and vertical planes. *J. Neurosci.* 35, 6051–6056.

[37] Voss P (2016) Auditory Spatial Perception without Vision. *Front. Psychol.* 7:1960.

[38] Voss, P. (2013). Sensitive and critical periods in visual sensory deprivation. Front. Psychol. 4:664.

[39] Lazzouni L. and Lepore F. (2014). Compensatory plasticity: time matters. Front. Hum. Neurosci. 8:340.

[40] Burton, H. (2003). Visual cortex activity in early and late blind people. J Neurosci *23*, 4005-4011.

[41] Merabet, L.B., and Pascual-Leone, A. (2010). Neural reorganization following sensory loss: the opportunity of change. Nat Rev Neurosci *11*, 44-52.

[42] Kolb, B. (1995). Brain plasticity and behavior (Mahwah, NJ: Lawrence Erlbaum Associates, Inc.).

[43] Kolarik AJ, Cirstea S, Pardhan S, Moore BC. (2014) A summary of research investigating echolocation abilities of blind and sighted humans. *Hear Res*, 310C:60–68.

[44] Jones, G., 2005. Echolocation. Current Biology 15, R484–R488.

[45] Brazier J. The Benefits of Using Echolocation to Safely Navigate Through the Environment International Journal of Orientation & Mobility. vol. 1, 2008.

[46] Thaler, L., Arnott, S.R., Goodale, M.A., 2011. Neural correlates of natural human echolocation in early and late blind echolocation experts. PLoS One 6, e20162.

[47] Kupersa,b, R. Maurice Ptito, M. 2014. Compensatory plasticity and cross-modal reorganization following early visual deprivation. Neuroscience and Biobehavioral Reviews 41, 36–52.

[48] Thaler, L., Goodale, M.A. (2016). Echolocation in humans: an overview. *Wiley interdisciplinary reviews. Cognitive science*. 7(6): 382-393

[49] Mordini E., Nierling L., Wolbring G., João Maia M., Bratan T., Capari L., Cas J., Hennen L., Krieger-Lamina J. and Kukk P. (2018) ‘Assistive technologies for people with disabilities. Part II: Current and emerging technologies’. EPRS | European Parliamentary Research Service, European Parliament.

[50]S. Paiva (ed.), Technological Trends in Improved Mobility of the Visually Impaired, EAI/Springer Innovations in Communication and Computing, Springer Nature Switzerland AG 2020.

[51]Brabyn J, Seelman K, and Panchang S (2007) Aids for people who are blind or visually impaired. In: Cooper R, Ohnabe H, and Hobson D (Eds.), An introduction to rehabilitation engineering, Taylor & Francis, pp 287-313

[52] Jimenez Javier, Jesus Olea, Jesus Torres, Inmaculada Alonso, Dirk Harder, and Konstanze Fischer, “Biography of Louis Braille and Invention of the Braille Alphabet”, Survey of Ophthalmology, v54, n1, p142-49, January-February 2009 Cattaneo, Z., & Vecchi, T. (2011). Blind vision: the neuroscience of visual impairment. Rehabilitation (p. 269). MIT Press.

[53] Tobin, M. J., Greaney, J., & Hill, E. (2003). Braille: issues on structure, teaching and assessment. In Y. Hatwell, A. Streri, & É. Gentaz (Eds.), Touching for knowing: cognitive psychology of haptic manual perception2 (pp. 237–254). Amsterdam- Philadelphia: John Benjamins Publishing Company.

[54] Wolffsohn S. J., and Peterson C. R., (2003) A review of current knowledge on Electronic Vision Enhancement Systems for the visually impaired. Ophthal. Physiol. Opt. 23: 35–42.

[55] Bray N., Brand A., Taylor J., Hoare Z., Dickinson C., and Edwards T. R., (2017) Portable electronic vision enhancement systems in comparison with optical magnifiers for near vision activities: an economic evaluation alongside a randomized crossover trial. Acta. Ophthalmol. 95: e415–e423.

[56] Domingo, M. C. (2012). An overview of the internet of things for people with disabilities. *Journal of Network and Computer Applications, 35*, 584–596.

[57] Ulrich I, Borenstein J. The Guide Cane-applying mobile robot technologies to assist the visually impaired. IEEE Trans Syst. Man Cybern A Syst Hum. 2002; 31:131e6.

[58] Dakopoulos, D., Bourbakis, N.G., “Wearable Obstacle Avoidance Electronic Travel Aids for Blind: A Survey” *Systems, Man, and Cybernetics, Part C: Applications and Reviews, IEEE Transactions on*, vol. 40, issue 1, pp. 25 – 35, 2010.

[59] Wittich W., Lorenzini Marie-Céline, Markowitz N., Tolentino M., Gartner S. A., Goldstein J. E., and Dagnelie G., The Effect of a Head-mounted Low Vision Device on Visual Function, Optom. Vis. Sci. 2018; Vol 95(9):774-784.

[60] Mills J.O., Jalil, A., & Stanga, P. E. (2017). Electronic retinal implants and artificial vision: journey and present. Eye (London, England) 31(10), 1383–1398.

[61] Fernandez E. Development of visual Neuroprostheses: trends and challenges. Bioelectron Med. 2018;4(1):12.

[62] Gekelera K., Bartz-Schmidtb K. U., Sachsc H., MacLarend R. E., Stinglb K., Zrennerb E., and Gekelera F. (2018) Implantation, removal and replacement of subretinal electronic implants for restoration of vision in patients with retinitis pigmentosa. 29(3):239-247.

[63] Elmannai W. and Elleithy K. (2017) Sensor-Based Assistive Devices for Visually-Impaired People: Current Status, Challenges, and Future Directions, Sensors (Basel, Switzerland). 17(3):565.

[64] A.M. Kassim, H. I Jaafar, M.A. Azam, N. Abas and T.Yasuno, Performances study of distance measurement sensor with different object materials and properties, 3rd IEEE International Conference on System Engineering and Technology (ICSET), pp. 281–284, 2013.

[65] S. Adarsh, S. M. Kaleemuddin, D. Bose, and K. I. Ramachandran "Performance comparison of infrared and ultrasonic sensors for obstacles of different materials in vehicle/ robot navigation applications," IOP Conference Series: Materials Science and Engineering, vol. 149, p. 012141, Sep 2016.

[66] Wahab, A.; Helmy, M.; Talib, A.A.; Kadir, H.A.; Johari, A.; Noraziah, A.; Sidek, R.M.; Mutalib, A.A. Smart Cane: Assistive Cane for Visually-impaired People. Int. J. Comput. Sci. Issues 2011, 8, 4.

[67] Fonseca, R. Electronic long cane for locomotion improving on visual impaired people: A case study. In Proceedings of the 2011 Pan American Health Care Exchanges (PAHCE), Rio de Janeiro, Brazil, 28 March–1 April 2011

[68] Kamaludina H. M., Mahmooda H.N., Ahmada H.A., Omara C., Md Yusofb A.M. (2015) Sonar Assistive Device for Visually Impaired People. *Jurnal Teknologi (*Sciences & Engineering) 73:6 (2015), 37–41.

[69] Mekala S., Niranjana Y., Prakash N., Gayathri D.S, Dharshini. V., Kishan. J., and Bhardwaj R., (2018) An Implementation of Obstacle and Image Detection Prototype Glove for the Blind, International Journal of Pure and Applied Mathematics. 118(20)3101-3107.

[70] Jones L, Lockyer B, and Piateski E (2006) Tactile display and vibrotactile pattern recognition on the torso. In: Advanced Robotics, vol. 20, pp 1359-1374.

[71] https://www.arduino.cc/

[72] M. Margolis, *Arduino Cookbook*, 2nd Edition, O'Reilly Media Inc., 2012.

[73] HC-SR04 Ultrasonic Sensor Module., User Guide: Ultrasonic Sensor V1.0, Available online: http://www.handsontec.com/pdf_files/hc-sr04-User-Guide.pdf (Accessed on 28 March 2020).

[74] Active buzzer datasheet, Available online: https://components101.com/sites/default/files/component_datasheet/Buzzer%20Datasheet.pdf (Accessed on 28 March 2020).

[75] Mohamed Kassim, A. et al. Conceptual design and implementation of electronic spectacle 18 based obstacle detection for visually impaired persons.Journal of Advanced Mechanical 19 Design, Systems, and Manufacturing, Vol. 10, No. 7, 2016, pp. JAMDSM0094.

[76] LM35 temperature sensor datasheet, Available online: https://www.ti.com/lit/ds/symlink/lm35.pdf (Accessed on 31 March 2020).

[77] KY-026 flame sensor module datasheet, Available online: https://moviltronics.com/wp-content/uploads/2019/10/KY-026.pdf (Accessed on 31 March 2020).

[78] DFPlayer Mini module datasheet, Available online: https://picaxe.com/docs/spe033.pdf (Accessed on 31 March 2020).

[79] Voice Recognition Module ELECHOUSE V3 datasheet, Available online: https://cxem.net/house/files/1-412_FZ0475.pdf. (Accessed on 5 May 2020).

[80] Power bank of 10000mAh User Manual., Available online: https://files.miot-global.com/files/power_bank_10000/powerbank10000-en.pdf. (Accessed on 10 August 2020).

[81] https://fritzing.org/

[82] https://www.naturalreaders.com/online/