A MULTI-DIMENSIONAL WALKING AID AND DESTINATION GUIDANCE SYSTEM FOR THE VISUALLY IMPAIRED

BY

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CERTIFICATION

I certify that this work was carried out by MMOJEKWU ECHEZONNACHUKWU CYRIL, with matric number 179481, in the department of Electrical and Electronics Engineering, University of Ibadan, under my supervision.

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DEDICATION

I dedicate this report to God, my parents and the department of Electrical and Electronic Engineering as a whole for making this project a success.

ACKNOWLEDGEMENT

I ascribe all recognition to the Almighty who has made me stronger through all my challenges in life and in the University. My profound appreciation goes to my motivating supervisor, Dr. O. O. Olakanmi for his continuous support and availability which was pivotal to the successful execution and completion of this project.

I sincerely wish to express my gratitude to my parents, Mr. and Mrs. Mmojekwu and my sisters for their relentless support and prayers in the course of my bachelors' program.

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ABSTRACT

Visually impaired users find it difficult to independently travel from their starting position to a specified destination without falling or tripping due to some stationary or moving obstacles and potholes in their path. Many guidance systems have been developed separately in the past few decades to mitigate or totally eradicate this problem for the visually impaired, but proved to be inefficient especially in terms of cost. Based on this need, a few navigation and obstacle detection systems have been proposed to guide its user through unknown environments.

The purpose of this work is to fill the void by proposing an efficient electronic travel aid for the visually impaired user. The proposed system uses a combination of GPS (in the android app and as a separate module), Ultrasonic and Lidar technology for navigation, obstacle detection and pothole detection respectively. This work includes a performance analysis and an evaluation of the proposed system against existing works with regards to safety of travel, operating speed, power consumption and cost.

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CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF STUDY

According to (GBD 2015 Disease and Injury Incidence and Prevalence, Collaborators), there were 940 million people with some degree of vision loss, 246 million had low vision and 39 million were blind. The number of moderate to severe visual impairment is said to triple by 2050 (BBC News, 03 August 2017) with most of the common causes globally being uncorrected refractive errors (43%), cataracts (33%), and glaucoma (2%) (Visual Impairment and Blindness Fact sheet, August 2014).

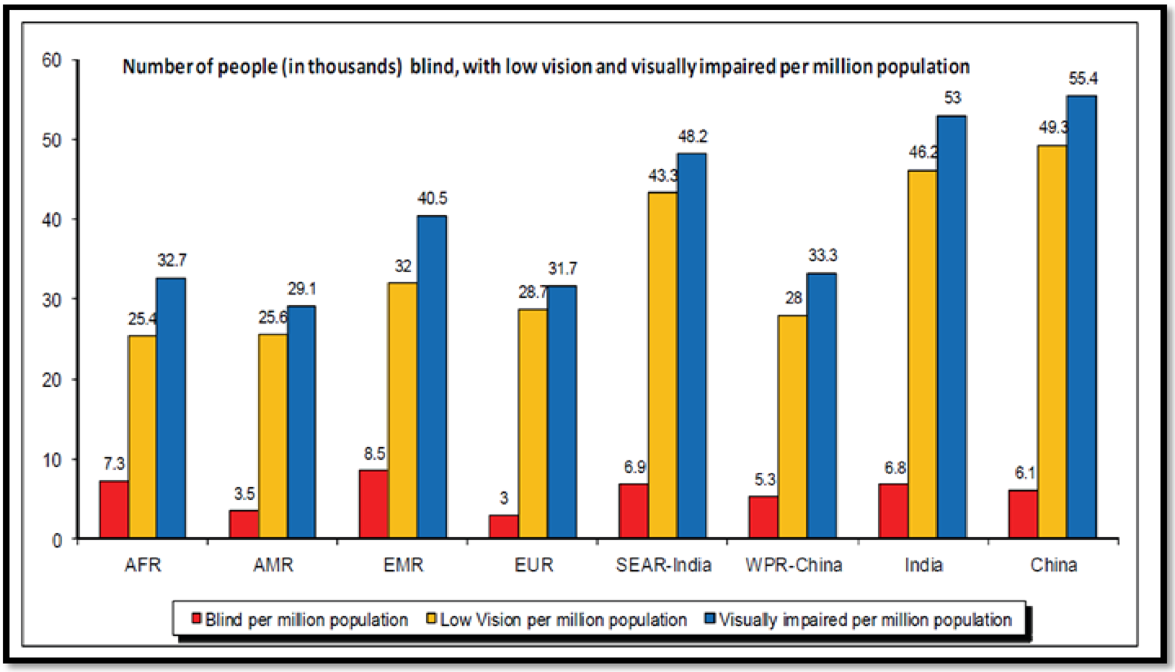

Fig. 1.1: Number of blind people with low vision and the visually impaired by WHO regions. (Global Data on Visual Impairments 2010, World Health Organisation.)

An individual is considered to be blind if he has central visual acuity of 20/200 or less in the better eye after best correction with contact lenses or glasses, or has a field of vision of less than 20 degrees in the better eye (Social Security Act, 2015).

To provide assistance to the visually impaired, orientation and mobility specialists are trained to teach people with visual impairments how to travel safely, confidently, and independently in the home and the community. These professionals also help blind people to practice travelling on specific routes which they may use often, such as the route from one's house to a convenience store to help them become familiar with that environment or route and make it much easier for the blind person to navigate successfully. Tools such as the long cane is used to extend the user's range of touch sensation. It is usually swung in a low sweeping motion, across the intended path of travel, to detect obstacles. However, techniques for travel can vary depending on the user and/or the situation.

1.2 PROBLEM STATEMENT

The (Nigerian National Blindness and Visually Impaired Survey) conducted between 2005 to 2007 estimated that 4.25million adults aged 40 years were visually impaired or blind.

In Nigeria, apart from human assistance, only few people with serious visual impairments can travel independently using high-tech products mostly due to the cost of the devices. The lack of visual capabilities has limited these individuals from being completely aware of their immediate surroundings which has lowered their quality of life since they must rely on some form of aid to navigate. Currently, in order for visually impaired individuals to travel, they rely on walking canes, guide dogs, and/or personal human aids for assistance. While these walking canes and guide dogs may allow the individual to travel independently, their common drawback is that they cannot completely warn individuals of obstacles in their vicinity. A human aid can, but this makes the visually impaired individual very dependent on the human aid who may not always be present.

1.3 AIM AND OBJECTIVES

The aim of this project is to develop a novel multidimensional walking aid with an effective and efficient navigation system for the visually impaired. In order to achieve this aim, the following objectives will be carried out:

1) To review existing works on walking aid for the visually impaired in order to extract the research gap.
2) To develop a light weight and cost-efficient walking stick that can alert the user of detected obstacles and potholes in the path of the visually impaired.
3) To carry out tests and performance analysis of the multidimensional walking aid on blind users.

1.4 METHODOLOGY

This work will be partitioned into different sections, the first of which is the development of an efficient obstacle and pothole detection unit for the blind. To achieve this, we will be making use of the ultrasonic sensor to detect obstacles in the path of the user, and the lidar sensor to detect potholes and alert the user. The next section will involve the development of Global Positioning System (GPS) location of the blind user to caretakers through a Short Message Service (SMS). The final phase of this work will then be the cost analysis of the proposed walking aid, this will include a comparison with existing walking aid for the blind.

1.5 CONTRIBUTION TO EXISTING KNOWLEDGE

A new pothole detection method is proposed in this work to address the challenges that visually impaired users face when trying to navigate their environment such as simultaneous pothole and obstacle detection, as well as a GPS guidance system which is the limitation of most walking aid.

1.6 ORGANISATION OF THE REPORT

We divide this work into five chapters, Chapter One contains the introduction of the work, which involves some background information on visual impairment, the problem statement, aim and objectives, and a brief summary of the methodology. Chapter Two is a literature review of existing works, here relevant information from credible sources are presented to give a foundation for this project. Chapter Three is made up of an extensive exposition of the methodology including the preliminaries and different phases of the work. In Chapter Four, results which include performance analysis with respect to cost of the work is provided. Chapter Five contains the conclusion and recommendation for future research towards improving on the current work done.

CHAPTER TWO

LITERATURE REVIEW

2.1 AIDS FOR THE VISUALLY IMPAIRED

Over several decades of development in technology, researchers have innovatively built electronic devices to provide the best non-human assistance possible to alleviate visual impairment. This chapter provides a review of several assistive technology to aid the visually impaired.

2.1.1 THE NON- ELECTRONIC AID

1) Long cane

The long cane is designed primarily as a mobility tool to detect objects in the path of its user which was introduced by World War II veteran rehabilitation specialist, Richard E. Hoover, at Valley Forge Army Hospital in 1944 (Koestler, Frances A., 2012). It effectively allows detection of obstacles within a 3-foot range and helps to warn other pedestrians to get out of the way. In addition, location cues from the sounds emitted when the cane tip (especially a metallic tip) contacts the ground can provide a surprising amount of the additional information regarding objects at the sides of the path. However, the skilled user of this cane is limited to the information of the obstacle on contact with the cane at close range.

2) Kiddie cane

This cane functions similar to the adult's long cane, but it's designed for use by children and hence smaller and lighter.

2.1.2 THE ELECTRONIC AID

Following the development of radar and sonar technologies for remote sensing during World War II and the introduction of transistor technology, which made portable electronic devices practical, inventors began to see the potential for various obstacle-detection devices to aid blind people. A huge number of such devices were developed, mostly using the transmission of an energy wave (usually ultrasonic) and the reception of echoes from objects in, or near the traveller's path. The choice of ultrasound for the transmission medium, as opposed to light or radio waves, was dictated by the convenience with which echo ranging could be performed in this medium due to the relatively slow speed of propagation.

Sonar technology, as it existed by 1960 was well developed for underwater purposes (Electronic Travel Aids, National Academy Press 1986), but its use above water was complicated by much-increased signal attenuation and the difficulty of coupling a transducer effectively to the air. These problems were overcome, and ultrasound became the most popular sensing medium for mobility aids. The main limitations of this technology were limited useful range and difficulties experienced with reflections from smooth surfaces (which act like mirrors to ultrasound due to its long wavelength).

Much later, the Global Positioning System (GPS) was introduced in the late 1980s (Factsheets: GPS Advanced Control Segment, 2011) and there have been many successful attempts in integrating it into a navigation-assistance system for the blind and visually impaired people.

The function of any sensory aid, as described by Dimitrios and Nikolaos (2010), is "to detect and locate objects and provide information that allows user to determine (within acceptable tolerances) range, direction, dimension and height of objects". A first level categorization of navigation systems for the blind during these developments is as follows:

i) Vision enhancement involves input from a camera which processes the information, and output the view on a visual display. In its simplest form it may be a miniature head-mounted camera with the output on a head-mounted visual display (as used in some virtual reality systems).

ii) Vision replacement involves displaying the information directly to the visual cortex of the human brain or via the optic nerve. We will not deal with this category since they deal with scientific, technological and medical issues whose study is beyond the purpose of this survey.

iii) Vision substitution is similar to vision enhancement but with the output being non-visual, typically tactual or auditory or some combination of the two and since the senses of touch and hearing have a much lower information capacity than vision, it is essential to process the information to a level that can be handled by the user.

The category that we will focus in this work is the "vision substitution." Here we can find these subcategories:

1) Electronic travel aids (ETAs):

ETAs are general assistant devices to help visually impaired people avoid obstacles by transforming information about the environment that would normally be relayed through vision into a form that can be conveyed through another sensory modality. The sensing inputs of ETAs are mainly classified into depth camera, general camera, radio frequency identification (RFID), ultrasonic sensor, and infrared sensor. Depth camera recognition systems captures images of the user's field of vision and analyzes the depth data of the images to predict the presence of obstacles ahead and alert the user of any such obstacles. Compared with purely two-dimensional images, depth images can provide more information about obstacles (Lin, Lee and Chiang, 2017). However, they cannot be used in environments with strong light. Moreover, depth cameras are more expensive than standard cameras and excessively large for convenient use; therefore, depth camera recognition systems are seldom used in actual applications. Regarding general camera recognition systems, such systems are designed to recognize tactile or obstacle images. General cameras do not to provide the depth information so that such systems cannot determine the distance from user to obstacle when used alone. General images usually are processed to detect only the obstacles ahead or guide visually impaired people walking along the tactile marks. General images similar to depth images need complex computing to hardly be implemented as a wearable guiding device or a guide cane.

Detecting distance sensors, such as RFIDs, ultrasonic sensors and infrared sensors, are usually used to modify guide canes. Regarding the RFID sensing method, an RFID reader module is installed on a guide cane, and a large quantity of RFID tags are positioned underground for positioning and navigation. Such assistive devices are not widely used and are difficult to apply in real-life situations; in addition, without large quantities of RFID chips being positioned underground in advance, the system cannot work. Regarding ultrasonic and infrared sensors, they are cheap and easily implemented into a guide cane. These kinds of sensors can precisely determine the distance and notify the visually impaired people there are obstacles in front, but they cannot recognize the obstacle categories. In more advanced design, multiple infrared sensors can detect special cases such as stairs, but still cannot detect the more complex shape of the obstacle.

ETAs are also sub-categorized into:

i) Visual-auditory substitution, that taxes a sensory modality by transforming the information gained from the environment into audio.
ii) The Tactile Vision Substitution (TVS) system is an important example of a TVS device. In this system visual information is captured with a video camera and delivered via a tactile array to the skin of the back, abdomen or thigh since the skin

is capable of representing information in two dimensions and integrating signals over time. With the TVS system, users were able to perform complex “eye”-hand coordination and facial recognition tasks (Dimitrios and Nikolaos 2010).

Furthermore, as with vision, these users learned to project the stimulus origin to a location distant from the site of stimulation. However, the TVS system proved to be inadequate for use in normal (cluttered) environments. Kaczmarek and Bach-y-Rita et al. (1998), postulated that the reason for this might be that the abundance of detail provided by the system overwhelms the information that is important for navigation in a complex environment.

2) Electronic orientation aids (EOAs):

EOAs are devices that provide orientation prior to, or during the travel. They can be external to the user and/or can be carried by the user, designed to aid visually impaired people for finding their way in an unknown environment. EOA systems usually need much environmental information to analyze the scope of the unknown environment. A combination of a camera and other multiple sensors e.g., infrared light transmitters, ultrasonic sensors, lidar sensors or auto-classification software on handheld devices is usually used to get more information to draw the shapes of passageway and obstacles and then providing the user with cues corresponding to orientation, relative position, direction and range, in a coded form, either audibly or through a tactile display.

Thus, since this system combine one or more technology, it may provide a more accurate guiding service and a recognition result of some obstacles. The drawback of EOAs is that they need more complex computing to be realized as a real-time and lightweight guiding device.

3) Position locator devices (PLDs):

PLDs which include technologies like GPS, European Geostationary Navigation Overlay Service (EGNOS), etc., are used to determine the precise position of its holder such as devices that use global positioning system (GPS) and geographic information system (GIS) technologies (Lin, Lee and Chiang, 2017). GPS and GIS-based guiding systems for blind people with user input interfacing (such as voice) intellectually find the current location and give the alert to the blind people if he arrives at his destination area. A pure GPS and GIS-based navigation system for general people are easily used to guide users from a current location to a destination. However, the pure GPS and GIS-based navigation system do not completely work in visually impaired people because the system cannot help user to avoid the obstacles in front of them. Thus, this kind of system usually need to collocate with other sensors to detect the obstacles. This system needs receive the signals from GPS satellites, so that they only can be used in outdoor, but not in indoor.

We are mostly interested in ETAs and more specifically in obstacle detection systems, not emphasizing in tactile features.

2.2 EXISTING WORKS ON WALKING AID

Blind Aid Stick has been a popular project with constant enhancements and modifications. As of now the economically accessible version of visually impaired stick are not that prominent because of high cost and absence of exactness. Within the scope of our project, previous work is analysed based on three sections; Obstacle detection, Navigation and Pothole detection. Although, most projects employed multiple technology to arrive at their solution.

2.2.1 NAVIGATION

1) Projects Using GPS Technology

The Pedestrian Navigation system proposed by Takashi and Nobuchika (2006), uses GPS for outdoor navigation and RFID tags for indoors. But this solution has proved to be inefficient due to the cost of the RFID reader and the installation of its tags. The RFID sensor is used for navigating the blind indoors and GPS is used for outdoor. For indoor navigation, the RFID sensor is attached to the walking stick of blind person and RFID tags are installed in all the areas that need to be identified. These tags serve as a landmark to the person using the cane. Each tag will be equipped with as much information as needed to clearly define the location of that precise tag (i.e. shops, names of places). The tag also contained additional information about direction and locations of other sensitive locations (i.e. Bus stops, telephone booths, subway stations, etc.). The RFID tag were covered by a protective shield to keep it safe from any harm. In outdoor, the GPS is used to find the location of the particular place. The GPS which is fixed to the walking stick of blind person will help to give location information in outdoor. The Fig.1 below shows the block diagram of the system.

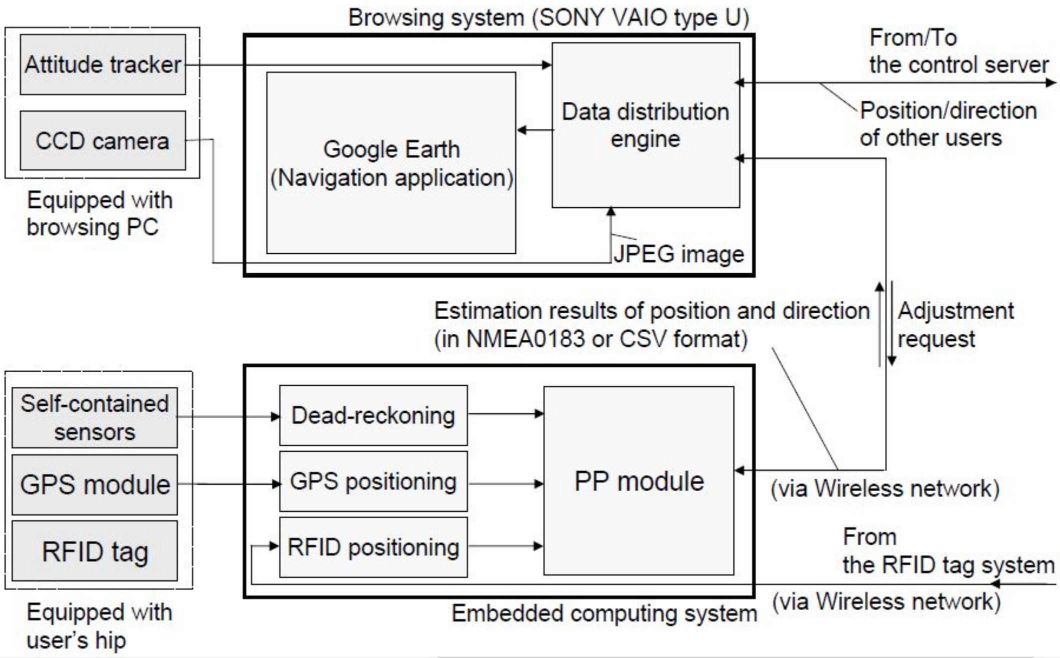

Fig. 2.1: Pedestrian Navigation System. (Takashi Okuma and G. M. Nobuchika Sakata, 2006).

Talking Signs, claims that Tactual identifiers are not suitable, because the blind traveller would need to tactually scan the environment just to know of their existence. Instead, they came up with identifiers that can be remotely sensed by the blind traveller using special equipment. One such system of remote signage currently being deployed in demonstration projects is what is known as Talking Signs (Crandall, Gerry, and Alden, 1993; Loughborough, 1979).

In the Talking Signs system, infrared transmitters are installed throughout the travel environment (e.g., subway station or airport). These highly directional transmitters continuously transmit digital speech indicating what is at the location of the transmitter (e.g., phone booth); within a range of 15 m or 40 m (depending upon battery size), a blind traveller with an infrared receiver can pick up the signal from the transmitter and hear the digital utterance; directional localization of the transmitter is possible by aiming the hand-held receiver to obtain maximum signal strength. A disadvantage of placing a network of location identifiers within the environment is the cost of installing and maintaining the network relative to the coverage achieved. One alternative is to use computer technology (e.g. the GPS) to locate the traveller and then make use of a spatial database of the environment to display to the traveller his/ her location relative to the environment.

The concept of Differential GPS and Virtual Acoustic Display to Convey Information to the Blind, is that as the blind person moves through the environment, he/she would hear the names of buildings, street intersections, and so on, ‘‘spoken’’ by a speech synthesizer, coming from the appropriate locations in auditory space as if they were emanating from loudspeakers at those locations. The plan was to use spatialized sound from a virtual acoustic display to convey information about the surrounding environment to the blind traveller. A virtual acoustic display takes a monaural audio signal (e.g., speech or sound effect) and transforms it into a binaural signal (heard by way of earphones) so that the sound appears to emanate from a given direction and distance (Begault, 1994; Carlile, 1996; Gilkey and Anderson, 1997; Loomis, Hebert, and Cicinelli, 1990; Wenzel, 1992; Wightman and Kistler, 1989). (The ‘‘head tracker’’ in this system consists of the DGPS receiver subsystem for position sensing and the fluxgate compass mounted on the earphone strap for sensing head orientation). The entire navigation system (computer, speech synthesizer, acoustic display hardware, and batteries) is carried in a backpack worn by the user. The major challenges to this project are that, the accuracy, realistic auditory distance perception of perceptual realism and localization for the two navigational functions of most interest: guidance of the traveler along a predefined route and providing the traveler with knowledge of the off-route environment is low and the total weight of the backpack and hardware is as heavy as 11.4 kg.

Tyflos navigation system was conceived by Bourbakis and workers in the mid-1990s and various prototypes have been developed (Banerjee and Gallagher et al.,2009). The Tyflos navigation system is consisted of two basic modules: The Reader and the Navigator (ETA).

The main goal for the Tyflos system is to integrate different navigation assistive technologies such as a wireless handheld computer, cameras, range sensors, GPS sensors, microphone, natural language processor, text-to-speech device, and a digital audio recorder, etc., and methodologies such as region-based segmentation, range data conversion, fusion, etc., in order to offer to the blind more independence during navigation and reading. The audio–visual input devices and the audio-tactile output devices can be worn (or carried) by the user. Data collected by the sensors are processed by the Tyflos' modules each specialized in one or more tasks. In particular, it interfaces with external sensors (such as GPS, range sensors, etc.) as well as the user, facilitating focused and personalized content delivery. The user communicates the task of interest to the mobility assistant, using a multimodal interaction scheme. The main role of the navigator is to capture the environmental data from various sensors and map the extracted and processed content onto available user interfaces in the most appropriate. Previous Tyflos prototypes are designed using many of the technologies mentioned above and tested yielding promising results. The latest Tyflos navigator system prototype developed in Wright State University consists of two cameras, an ear speaker, a microphone, a 2-D vibration array vest (attached on the user's abdomen) controlled by a microprocessor, and a portable computer, and it integrates various software and hardware components. The stereo cameras create a depth map of the environment (which can be verified by the range sensor's output). A high-to-low resolution algorithm drops the resolution of the depth map into a low resolution, keeping necessary information for navigation such as safe navigation paths and objects of interest (moving objects and people, using motion detection and face-detection methodologies). This final "image" is a representation of the 3-D space, and it is converted into vibration sensing on a 2-D vibration array/vest that is attached on the user's abdomen or chest. The element of the array that vibrates represents the direction, where an object is detected and the different vibration levels represent the distance of the object. Optional audio feedback can inform the user for objects of interest.

The main advantages of the Tyflos are that is free-ears and that the use of the 2-D vibration array with the variable vibration frequencies offers the user a more accurate representation of the 3-D environment (including ground and head height obstacles) giving also information for distances. The disadvantages are that the system is not yet tested on blind users, which is an important step for receiving feedback for future hardware and software changes.

The idea of using GPS to assist the visually impaired with navigation goes back over a decade, when Collins (1985) and Loomis (1985) independently proposed it. The first evaluation of GPS for this purpose was carried out by Strauss and his colleagues (Brusnighan et al., 1989); because their research was conducted at an early stage of GPS development, the poor positioning accuracy they obtained precluded practical studies with blind subjects.

Sainarayanan *et al.* from University Malaysia Sabah developed an ETA (sound-based) to assist blind people for obstacle identification during navigation, by identifying objects that are in front of them. The prototype navigation assistance for visually impaired (NAVI) is consisted of a digital video camera, headgear (holds camera), stereo headphones, the single-board processing system (SBPS), rechargeable batteries, and a vest (that holds SBPS and batteries). The idea is that humans focus on objects that are in front of the centre of vision and so it is important to distinguish between background and obstacles. The video camera captures grayscale video, which is resampled to 32×32 resolution. Then using a fuzzy learning vector quantization (LVQ) neural network the pixels are classified to either background or objects using different grey level features. Then the object pixels are enhanced and the background suppressed. The final stage cut the processed image into left and right parts, transform to (stereo) sound that is sent to the user through the headphones.

Blind persons were trained with simulated experiments and then asked to identify obstacles of indoor environment, and they were able to identify slowly moving objects. Although the distance of objects was not (and is not) aimed to be identified, is possible to be done by the change of an object's shape, e.g., when the user approaches an object, its size will become bigger. The advantage of this system that the prototype is developed and it is operational and real time. The disadvantages are the use of audio feedback and that no information about the distances of objects is given.

2) Projects Using Ultrasonic Technology

Guidecane is the second project by Borenstein and Ulrich (1997), and it serves as an update for Navbelt. It is a device that the user can hold like a white cane and that guides the user by changing its direction when an obstacle is detected.

The sketch of the prototype is a handle (cane) is connected to the main device. The main device has wheels, a steering mechanism, ultrasonic sensors, and a computer.

The operation is simple: the user moves the Guidecane, and when an obstacle is detected the obstacle avoidance algorithm chooses an alternate direction until the obstacle is cleared and route is resumed (either in a parallel to the initial direction or in the same). There is also a thumb-operated joystick at the handle so that the user can change the direction of the cane (left or right). The sensors can detect small obstacles at the ground and sideways obstacles like walls. Compared to the competitive ETAs, the Guidecane does not block the users hearing with audio feedback and since the computer automatically analyzes the situation and guides the user without requiring him/her to manually scan the area, there is no need for extensive training. The drawbacks are the limited scanning area since, small or overhanging objects like pavements or tables cannot be detected and that the prototype is bulky difficult to hold or carry when needed.

2.2.2 OBSTACLE DETECTION

1) Projects Using Computer Vision

Vision systems are widely used for object detection and constitute a feasible option to be implemented separately or along with Lidar. Most of the object detection and tracking systems apply a simple segmentation procedure like background subtraction or temporal difference to detect objects. But these approaches have a weakness related to the background changes due to the camera motion. Papageorgiou and Poggio (2000), introduced a trainable object detection architecture based on a novel idea of the wavelet template that defines the shape of an object in terms of a subset of the wavelet coefficients of the image.

Motivated in part by this architecture, Viola et. al. (2001) presented a machine learning approach for object detection, which is suitable for real-time operation while achieving high detection rates, using Haar-like features and an AdaBoost classifier. However, this system used heavy and expensive equipment which would be a serious burden to a blind person.

Adjouadi from Florida International University (2008) worked on a computer vision project in order to exploit, in an optimal fashion, the information acquired by cameras to yield useful descriptions of the viewed environment. Then, efficient and reliable cane cues can be sought in order to improve the mobility needs of individuals with visual impairments. The system is consisted of digital cameras and a microcomputer, which is equipped with software for detection of depression or drop-offs, discrimination of upright objects from flat objects, identification of shadows, identification of special objects (staircase, crosswalk, doorway, etc.), planning of safety path/direction. This project is not yet to be considered as an operational ETA since issues, as how the user will be informed during navigation are still open, but the algorithms are specially designed and implemented for navigation of blind and visually impaired. The author proposed audio verbal messages or tactile devices. As far as the software part, the strong points are that the algorithms were tested with good results since many special cases are considered (staircases, vertical edges, depressions, etc.) with the limitation that there should be good-lightning conditions.

The objective of Johnson and Higgins from University of Arizona was to create a wearable device that converts visual information into tactile signal to help visually impaired people self-navigate through obstacle avoidance. The prototype is named tactile vision system (TVS) and is consisted of a tactor belt with 14 vibrator motors spaced laterally, a camera belt with two web cameras attached and a portable computer carried in a backpack.

A 2-D depth map is created using the images from the two cameras. Then it is sliced in 14 vertical regions. Each vibrator motor is assigned one region and the value of the closest object in each region is transformed to vibration. Vibration frequency and distance of object are nonlinear (increases dramatically for closer objects) and very far or very close objects are ignored. Information given by the tactor belt is applied on the skin of the abdomen (flat, large, easily accessible, no interference with other navigation functions of user). Video is captured with rate up to 10 frames/s, which makes the system real time for normal walking speeds.

The major advantages of TVS are that it is wearable, it gives user free hands without blocking hearing, and it operates in real time. The disadvantages are that it cannot differentiate between overhanging and ground obstacles and that no real experiments with visually impaired people have been performed. Future works consists of using different stereovision algorithms, different configuration of the tactor array and a possible very large-scale integration (VLSI) implementation. In addition, studies will be performed on what type and what quantity is minimally necessary for navigation and what is the point of saturation beyond which perceptual improvements are minimal.

The electron-neural vision system (ENVS) by Meers and Ward from University of Wollongong in Australia aims to achieve obstacle avoidance and navigation in outdoor environments with the aid of visual sensors, GPS, and electrotactile simulation. The prototype is consisted of a headset with two stereo cameras and digital compass, a portable computer with GPS capabilities and database of landmarks, the transcutaneous electrical nerve stimulation (TENS) unit (microcontroller), and the TENS gloves.

The basic concept behind the ENVS prototype is the stereo cameras, using stereoscopic vision, create a depth map of the environment and using the portable computer, information regarding the obstacles (from the depth map) or landmarks (from GPS) is transformed via TENS to electrical pulses that stimulate the nerves in the skin via electrodes located in the TENS data gloves. The user perceives the information if imagines that his/her hands are positioned in front of abdomen with fingers extended. The amount of stimulation is directly proportional to the distance of the objects in the direction pointed by each finger.

The prototype was tested with blindfolded users in outdoor campus environment, working in real time (video of 15 frames/s). With a minimum training (1 h) the users were able to report the location of obstacles, avoid them and arrive at a predefined destination. The system is one of the most complete in this survey because it is portable, real time, it has GPS capabilities, it does not block user's hearing, and the first experimental results are very promising. Some of the drawbacks are that the ground or overhanging objects are not detected, that a flat path is required (i.e., no stairs or drop-offs) and that the user is required to wear the TENS gloves.

A portable–wearable system that assists blind people orienting themselves in indoor environments was developed by researchers in University of Stuttgart in Germany. The prototype is consisted of a sensor module with a detachable cane and a portable computer. The sensor is equipped with two cameras, a keyboard (similar to those in cell phones), a digital compass, a 3-D inclinator, and a loudspeaker.

It can be handled like a flashlight and "By pressing designated keys, different sequence and loudness options can be chosen and inquiries concerning an object's features can be sent to the portable computer. After successful evaluation these inquiries are acoustically answered over a text-to-speech engine and the loudspeaker."

The computer contains software for detection of colour detection distance and size of objects and wireless local area network (WLAN) capabilities. The device works almost in real time. In order to improve the performance of the system, a virtual 3-D model of the environment was built, so the information from the sensor can be matched with the data stored in the 3-D model. A matching algorithm for sensor information and 3-D model's data and embedding the system to Nexus framework (a platform that allows a general description of arbitrary physical real-world and virtual objects) are the future work proposals.

The system's positives are the robustness of the sensor, the near real-time operation and the friendliness to the user. The negatives are that the hold-and-scan operation and the limited, simulated testing.

Meijer (2014) started a project vOICE, having the basic argument that human hearing system is quite capable of learning to process and interpret extremely complicated and rapidly changing sound patterns. The prototype consists of a digital camera attached to conventional eyeglasses, headphones, and a portable computer with the necessary software.

The camera captures images and the computer uses a direct, unfiltered, invertible one-to-one image-to-sound mapping. The sound is then sent to the headphones. No filters were used to reduce the risk of filtering important information since the main argument is that human brain is powerful enough to process complex sound information. The system is very simple, small, lightweight, and cheap. Lately, the software was embedded on a cell phone, and thus the user can use the cell phone's camera and earphones. In addition, sonar extension is available for better representation of the environment and increased safety. Many individuals tried the system returning very promising feedback, but they required extensive training because of the complicated sound patterns.

Bouzit and co-workers from State University of New Jersey developed the tactile handle, a device that will help visually impaired people navigate in familiar and nonfamiliar environments without any assistance. The prototype is a compact (5 cm×5 cm×20 cm), lightweight, ergonomic, low-power (80 h autonomy) handheld device. It embeds a microcontroller, a 4 × 4 tactile arrays, where each actuator matches one finger phalanx, and 4 sonar sensors, which detect obstacles in the front, left, right, and bottom. Information about the obstacles is given in an encoded form through the actuators.

The location of the feedback represents different direction of the obstacle. The intensity represents different distance and the timing of the feedback makes the user feel more comfortable and helps him/her understand dynamic aspects of the environment such as speed. Simple experiments with blind-folded users were performed in controllable indoor environments. The results show that training is necessary and the device can perform as an obstacle detection system. The contributions of this project are mostly the development of low-power ergonomic and compact prototype actuators, which do not block the user's hearing. On the other hand, it requires from the user to constantly scan and use one of his/her hand. Furthermore, the results show that excessive training is necessary.

Zelek with students from University of Guelph in Canada, developed an inexpensive, built with off-the-shelf components, wearable and low power device that will transform depth information (output of stereo cameras) into tactile or auditory information for use by visually impaired people while navigation. The prototype consists of two stereo cameras, a tactile unit (glove with five piezoelectric buzzers on each fingertip), and a portable computer. Each finger corresponds to a spatial direction. For example, the middle finger corresponds to straight ahead. Using a standard stereovision algorithm, the depth map is created and then divided into five vertical sections, each one corresponding to a vibration element. If a pixel in an area corresponds to a threshold distance (here 3 ft) then the corresponding vibration element is activated, informing the user about a close obstacle in that direction. The low power/cost is the pros but the lack of sophisticated methodologies (e.g., the stereovision algorithm needs improvement) does not offer interesting results.

2) Projects Using RFID Technology and Android

In the Electronic Stick and Android Smart Telephones to Aid the Blind proposed by Rajesh and Jagadeesh et al. (2018), the framework is predominantly made out of a Renesas microcontroller (RL78), LCD, Temperature sensor, RFID and RFID labels, Bluetooth module connect with mobile, Ultrasonic sensor, Water sensor.

The microcontroller situated at the centre point of the block diagram frames the control unit of the whole project. Once the whole unit (including microcontroller and sensors) is worn by the visually impaired the sensors start to monitor the surrounding environmental conditions. The yield of the sensors is a voltage which compares to the surrounding environmental conditions. This voltage created by the sensors is fed to the inputs of the microcontroller. In this situation ultrasonic sensor contribution to the microcontroller. In view of the program inserted inside the controller a yield is produced and transmitted to the Android based Smartphone by means of Bluetooth module. An application made and stored in the Android based Smartphone, creates speech yield depending upon the approaching messages transmitted by means of Bluetooth.

Ultrasonic sensor is used to find the separation of any object from the visually impaired. This can come close by for people with poor sight because of ageing factor. In the event that any object is situated inside the range of 20cm or 30cm, the sensor on recognizing the nearness of the obstruction conveys an input voltage to the microcontroller which at that point alarms the visually impaired by means of Android Smartphone using Bluetooth module.

3) Projects Using Ultrasonic Technology

The method proposed by Manoj and Rhoni (2017) uses the Sona Switch TM1700 Ultrasonic Sensor as the primary segment of the project. This sensor utilizes a beam of ultrasonic waves to determine the separation to the obstacle in progress. The sensor has two fundamental components: 1) a DC: voltage yield that is a straight simple of the separation measured and 2) an internal switch. These two elements are utilized to create a framework that capacities in a simple or computerized method of location.

The simple method of recognition was refined by utilizing the DC voltage yield of the ultrasonic sensor. Utilizing PC alignment programming, the sensor was adjusted by means of a RS-232 serial port to deliver a DC voltage yield running directly from five Volts on items distinguished at 1.5 feet or less to zero Volts on articles recognized at twelve feet or more. The simple voltage created by the sensor was associated with the voltage input (stick 4) (of the AD654 Monolithic Voltage-to-Frequency Converter. The AD654 (Analog Devices, Norwood, Massachusetts) is a solid voltage-to-recurrence converter comprising of an info intensifier, an accuracy oscillator framework, and a high current yield organize all consolidated into a solitary eight stick DIP chip. The AD654 changes over the DC voltage from the Sona Switch into an AC square wave recurrence. This recurrence yield (stick 1) was then associated with two little earphone speakers consequently delivering a discernible recurrence of tweets that fluctuated relatively with changes in protest discovery remove.

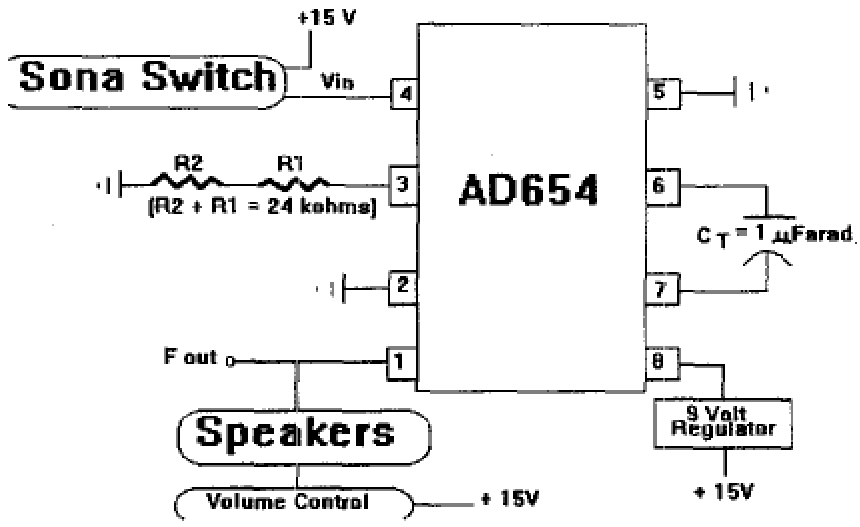

Fig. 2.2: Sona SwitchTM1 700 Ultrasonic Sensor (Manoj BG and Dr. Rohini V, 2017)

The recurrence yield of the AD654 changed relatively to the yield voltage from the Sona Switch 1700 Ultrasonic Sensor With a voltage contribution of five Volts, a recurrence of twitters yield of 20.8 Hz could be accomplished. The computerized method of location was expert by utilizing the interior switch of the ultrasonic sensor and by introducing an outer hardware switch. The outer switch disengages the simple DC voltage yield line driving from the ultrasonic sensor into the AD654 voltage input (stick 4). In the meantime, the outside switch reconnects the voltage input (stick 4) to a five Volt controller, and transfers the AD654 ground (stick 2) through the interior switch of the sensor. Upon protest discovery, the inward switch closes permitting current to deplete from the five Volt controller through the AD654 into ground. However, this method is not very accurate and the ultrasonic sensor which is the major component cannot tell the type of obstacle.

Cardin *et al.* from Ecole Polytechnique F´ed´erale de Lausanne -EPFL (2005) developed a wearable system that detects obstacles on shoulder height via a stereoscopic sonar system and sends back a vibrotactile feedback to inform the user about its localization. The prototype consists of sonar sensors, a microcontroller, eight vibrators, and a calibration console (PDA).

The microcontroller gathers information from the sonars proportional to the distance of the obstacle detected. It calculates the approximate distance of the obstacle and then converts the distance to a pulse width modulation (PWM) signal that is redirected to the vibrators (different vibration speeds), so that the user can be informed for the detection.

The sonars and the vibrators are mounted on the clothes of the user, starting from one shoulder and ending to the other. Finally, the calibration console communicates with the microcontroller via Bluetooth and allows dynamical modification of the calibration curve (real distance between object and sensor). Experimental results were obtained by testing the device in a controlled indoor environment (corridor with people walking and doors opening and closing) on 5 users. The results were encouraging since the users managed after a small training to walk through the corridor, distinguish obstacles (which are on the left or on the right side) and localize themselves in the corridor.

The pros of this project are that it is a wearable light, low power consumption, and low-cost system. The cons are that is not tested on visually impaired people and that four sonars cannot represent adequately 3-D space (different heights). Another practical problem mentioned by the authors is the interference of hands and their detection as obstacles.

A multidimensional walking stick for the visually impaired individual proposed by Dr. O. O. Olakanmi (2014) utilizes ultrasonic sensors equipped for identifying the heading and position of obstacles. The execution and usefulness are enhanced by the expansion of ready light, and voice direction signal which is handed-off to a smaller than expected headset. Equipment utilized as a part of the execution of the framework are ISD 2590 voice record/playback chip, PIC16F887 microcontroller, ultrasonic sensors, voltage controller, and speakers (headset and amplifier). The recorded voice alerts the client of the nearness and heading of the obstacle(s). Though the model of the multidimensional walking stick help to identify obstacles inside the scope of 0m to 1m at the left, right and front of the stick with a voice alarm, but the range of detection of obstacles is low, that is, 1-meter maximum range of detection.

In the Obstacle Detection Using Ultrasonic Sensor and Raspberry Pi (Anushree and Chitra, 2015), obstacles were detected using ultrasonic sensor, and raspberry pi to calculate the distance from the object according to the time difference between the emitted and received beam and programmed such that the system reads out "Obstacle detected". The destination address from the user was obtained using a microphone, Text to speech using Google Voice Recognizer API, Route querying by getting the blind user's current Co-ordinate from GPS and the destination Co- ordinate from a predefined database and computing the route, Obtaining the geocoded address using a GEO-CODER and finally the outputting of the pedestrian route to speech using Espeak speech synthesizer.

This model has the capability to guide the blind user to his destination, but has low accuracy and must have a predefined set of locations in its database.

Virtual acoustic space was developed by researchers in Instituto de Astrof´ısica de Canarias (IAC). A sound map of the environment is created and so the users can orientate by building a perception of space itself at neuronal level.

The prototype is consisted of two-colour micro cameras attached to the frame of some conventional eyeglasses, a processor and headphones. The cameras, using stereoscopic vision, capture information of the surroundings. The processor, using HRTF (Head Related Transfer Function- a response that characterizes how an ear receives sound from a point in space), creates a depth map with attributes like distance, colour, or texture and then generates sounds corresponding to the situation in which sonorous sources exist in the surroundings. The experimental results on visually impaired people showed that in most cases (>75%), individuals could detect objects and their distances and in small simple experimental rooms, it was possible for them to move freely and extract information for objects like walls, table, window, and opened door.

The major advantage of this system is that the eyeglasses are convenient and the size of the processor is small (like a portable CD-player). The major disadvantage is that is not tested in real environments.

The smart stick developed by Navigation and Radhika R. (2016), as shown in Fig. 2.3, is basically an embedded system integrating the following: a pair of ultrasonic sensors to detect obstacles in front of the blind from ground level height to head level height of the stick in the range of 400 cm ahead, infrared sensor to detect upward and downward stairs, water sensor for detecting puddles. The sensors collect the real-time data and send it to the microcontroller for processing. After processing, the microcontroller invokes the right speech warning message through a Bluetooth earphone. The system is powered by a rechargeable battery.

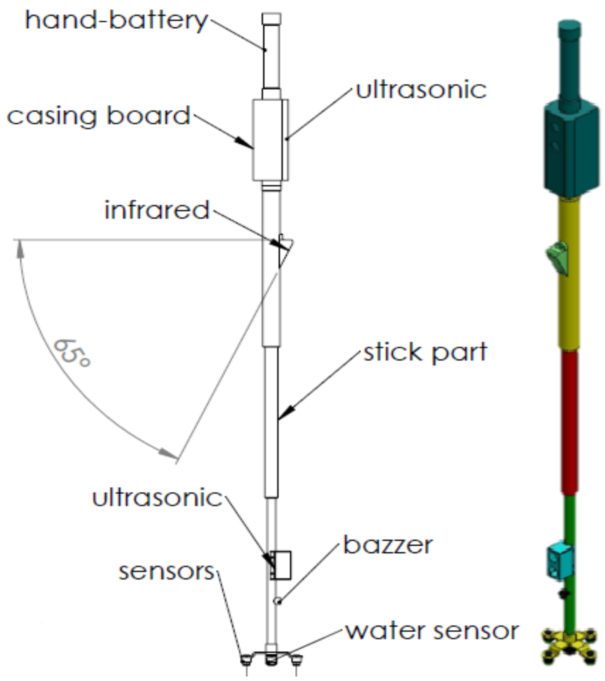

Fig. 2.3: Design of the Smart Stick (Implementation of Smart Stick for Obstacle Detection and Navigation, Radhika R. 2016)

The GPS based blind device with user input interfacing get alert the blind person when he reaches his destination by voice. This consists of microcontroller module, GPS Unit and a voice module to generate voice output. It stores the data of the current location which it receives from the GPS system, so that it can make use of the data stored to compare with the destination location of the user. By this it can trace out the distance from destination and produce an alarm to alert the user in advance.

CyARM was developed by researchers in Japan (Future University-Hakodate, Kanazawa University, Ochanomizu University and Fuji Xerox Company Ltd., 2005). It is an aid for use in guiding orientation and locomotion, using a nonstandard interface: ultrasonic sensors detect obstacles and calculate their distance from the user. The user is informed about the distance via the tension of a wire that is attached on him (e.g., his belt): high tension indicates close distance (the user can reach the obstacle by extending his/her hand), while a lower tension indicates longer distance.

The prototype is a handheld device weighting 500 g. It contains a microcontroller that processes the information from the sensors and operates a geared motor/reel that controls the tension

of the wire. Small-scale experiments were performed to evaluate CyARM's efficiency in detecting obstacles, navigation through paths and target tracking. The results for the obstacle detection and navigation through tasks were promising since more than 90% of the times the subjects were able to detect the large obstacles placed in front of them or to judge if it is possible to navigate through two of them. On the contrary, the moving target tracking results were not so encouraging.

The system's major advantage is its easy-to-learn (as the authors claim) alternative interface. The main disadvantages are that the user needs to hold it and scan the environment continuously and the lack of many experimental results with visually impaired users.

The 'K' Sonar model 1-07000-00 is a small audible electronic mobility aid and obstacle detector with the size of cell phone, designed for use by individuals who are blind or have low vision. It also uses ultrasonic sensor to detect obstacles in its path. (Terrie Terlau et. Al, 2008) Headphones provide audio feedback, which changes in pitch to indicate the distance to the object being scanned. By listening to sounds produced by the device, users can determine the distance and location of objects and some of the object's features. The device attaches to the golf grip handle of a long cane. It as well has the limitation of not detecting the kind of obstacle.

Researchers in Florida International University (FIU) (2012), developed an obstacle detection system that uses 3-D spatialized sounds based on readings from a multidirectional sonar system. The prototype consists of two subsystems: the sonar and compass control unit, which is consisted of six ultrasonic range sensors pointing in the six radial directions around the user and a microcontroller; and the 3-D sound rendering engine, which is consisted of headphones and a personal digital assistant (PDA) equipped with software capable of processing information from the sonar and compass control. The algorithm, using head-related transfer functions (HRTF), creates a 3-D sound environment that represents the obstacles detected by the sensors. The user in that way creates a mental map of the layout of his/her surroundings so that obstacles can be avoided and open passages can be considered for path planning and navigation. The system was tested on four blind-folded individuals, who were asked to navigate in a building. The results were promising but the navigation speed was slow.

Chukwunazo and G. M. Onengiye (2015) outlined and executed a microcontroller-based portability help for visually impaired individuals. Their proposed stick comprises of unique discovery sensors incorporated to AT89C52 microcontroller for accepting, preparing and sending signs to the alert framework. The framework was planned, customized with low level computing construct and tried for exactness and checked by the outwardly hindered individual. The equipment utilized comprises of AT89C52 microcontroller, sensors (Ultrasonic, water, and light ward resistor, LDR), and alarm. Their mobility aid designed for blind people is affordable, reliable and easy to operate.

The framework comprises of an ultrasonic sensor for deterrent location, a water sensor for water identification in dangerous regions and a light ward resistor for darkness recognition. The cost viability of the proposed arrangement prompts bargains in execution. The proposed strategy is a minimal effort and light weight framework composed with a microcontroller that processes signals and alerts the blind individual over any obstacles, water or dark areas through beeping sounds. Their exploration work centres around obstacle detection, light identification and water recognition so as to diminish route troubles for visually impaired individuals. However, the water sensor limits the project to the user being in contact with a waterlog which puts the user at risk of slipping.

The main goal of the Echolocation project, which started in the early 1990s in Japan, was to design a new mobility aid modelled after the bat's echolocation system. Two ultrasonic sensors are attached on conventional eyeglasses and their data, using a microprocessor and A/D converter, are down-converted to a stereo audible sound, sent to the user via headphones. The different intensities and time differences of the reflected ultrasound waves transmitted by the sensors indicate the different directions and sizes of obstacles, creating a form of localized sound images.

Some preliminary experiments were performed to evaluate the user's capability to discriminate between objects in front of the user's head, using different ultrasound frequencies. The results provided show that the users can identify and discriminate objects in some limited cases, but more experiments and statistical results are required to support the viability of the project. The simplicity and portability of the prototype are also major advantages.

Navbelt was developed by Borenstein and coworkers in University of Michigan (1989) as a guidance system, using a mobile robot obstacle avoidance system. The prototype as implemented in 1992 and it is consisted of ultrasonic range sensors, a computer and earphones. The computer receives information from the eight ultrasonic sensors and creates a map of the angles (each for every sensor) and the distance of any object at this angle. Then the obstacle avoidance algorithm (including noise reduction algorithm EERUF) produce sounds appropriate for each mode.

Navbelt has two modes: the guidance mode and the image mode. During the guidance mode, the computer knows the user's destination and with a single recurring beep guides him/her in the generated optimal direction of travel.

But in practice, a realistic (non-simulation) implementation would require more sensors. In the image mode, eight tones of different amplitudes are played in quick succession from eight different virtual directions (similar to a radar sweep). The computer translates (depending on the mode) these maps to sounds that the user can listen from his earphones. The disadvantages of the systems are the use of audio feedback (exclusively), the bulky prototype and that the users are required extensive training periods.

4) Projects Using Laser Technology

Manduchi and Yuan (2004) from University of California Santa Cruz (UCSC) developed a noncontact handheld tool for range sensing and environment discovery for the visually impaired.

The basic argument is that a perception through exploratory movements (similar to those using a white cane), appears to be a natural procedure for environment discovery. Thus, the tool is handheld and as the user swings it around (vertical or horizontal) he/she will receive information by means of tactile devices. The system deals only with 1-D data, which is computationally cheaper than computer vision or spatial sound techniques. The prototype is consisted of a laser range sensor (point laser matched with a matrix CCD), and a computer. The range sensor is based on active triangulation. In addition, the time profile of the range is analysed by the computer to detect environmental features that are critical for mobility, such as curbs, steps, and drop-offs, by means of an extended Kalman filter tracker. The detection technique used works for detecting planar structures. The system is reliable for local range measurements and gives promising environmental features detection. In addition, although it is handheld, it is small and easy to carry. The disadvantages are that it is not tested with visually impaired people, there is no interface between device and user and that it is constraint in the detection of only planar structures and objects near the ground. Some of the future improvements that are proposed by the authors are improvement of feature detection algorithms; replace of point laser with laser striper; built in processor in the device will replace computer; and tactile devices that will inform user for features detected.

2.2.3 POTHOLE DETECTION

Projects Using Computer Vision

In the through vision tracking for automated pavement assessment, by Christian and Ioannis from Georgia Institute of Technology (2011), once a pothole is detected in a video frame, the corresponding region is tracked in the subsequent frames until it leaves the viewport. To achieve that, the detection algorithm is suspended and the detected pothole region is marked as the region of interest rectangular box. This rectangular area is then committed to the pothole tracking algorithm that tries to trace this region within the subsequent frames. Once the region of interest leaves the viewport the tracking algorithm is stopped, the detection algorithm is resumed and the number of detected potholes is incremented. The tracking algorithm has to be performed on every frame independently, and in case of multiple potholes, it is executed in parallel. This project tracks potholes, but doesn't inform the visually impaired of its distance on time.

2.3 DRAWBACK ON THE ABOVE DEVICES

Most of these devices mentioned above work great at one task. A few devices provide GPS directions and the others sense impeding obstacles but none of them detect potholes ahead and inform the visually impaired.

In summary, according to the implementations in these studies, assistive devices for navigation for visually impaired people do not consider pothole detection or only focus on pothole detection only. Moreover, distance sensing cannot provide additional information to help visually impaired people to understand their surroundings. Therefore, the practicability of such assistive devices is very low. Some solutions using RFID chips are expensive and vulnerable to damage from the sun and rain. Therefore, the current study proposes a navigation system for visually impaired people; this system employs a smartphone and deep learning algorithms to recognize various obstacles. The proposed system is not limited to specific indoor or outdoor environments and does not require the positioning of RFID chips in advance. Thus, the proposed system not only increases the number of available locations, but also provides more information for visually impaired people about their surroundings.

CHAPTER THREE

METHODOLOGY

3.0 INTRODUCTION

The design and implementation of the multi-dimensional walking aid is discussed in this chapter. This Electronic Travel Aid (ETA) is designed to detect obstacles and potholes ahead of the visually impaired user, as well as providing navigation to the user through auditory and vibro-tactile feedback. Each stage of the design is well-described with illustrative diagrams, equations and circuit diagrams. The block diagram of the system design is given in Figures 3.1 and 3.2.

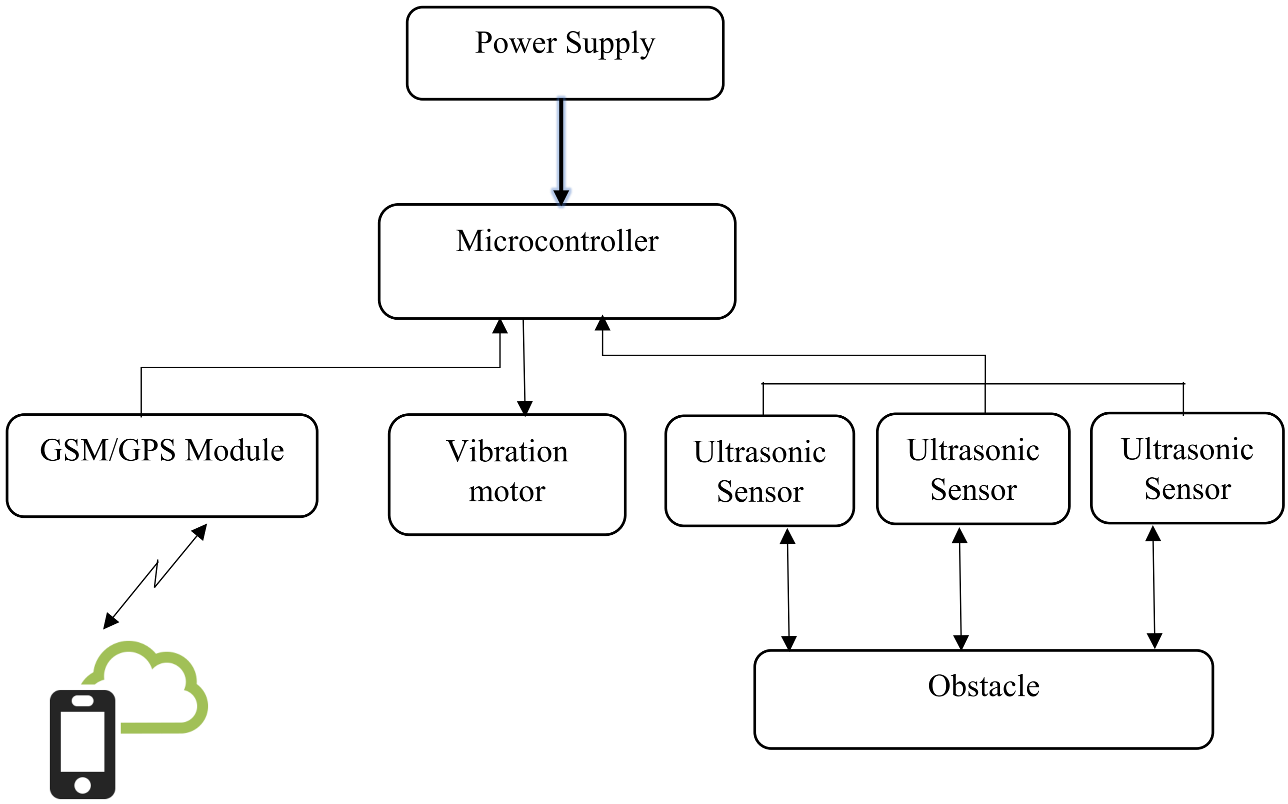

Figure 3. 1: Block Diagram of the Electronic guide cane Design

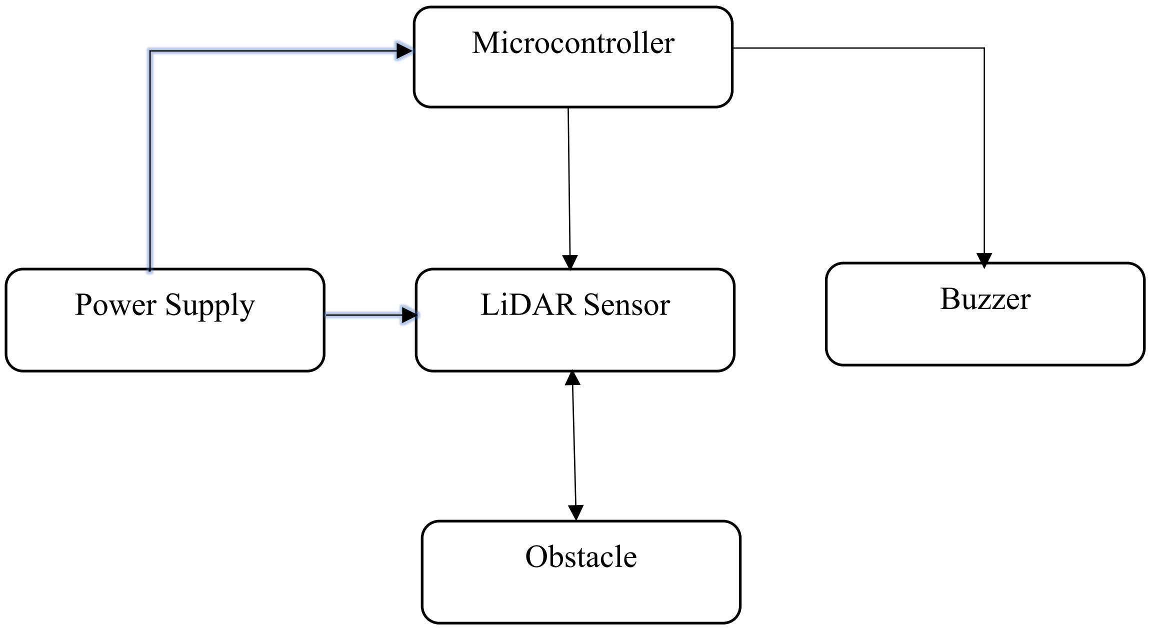

Figure 3. 2: Block Diagram of Electronic glasses Design

3.1 DESIGN CONSIDERATION

In designing the electronic walking aid devices, some factors were taken into consideration as a form of guidance in the process of fabrication. These include:

1. Overall Function:
   i. Should alert user of impeding obstacles and potholes while walking.
   ii. Should direct users using GPS to their desired location.
2. Cost: The components used in the device should be cheap. The overall design and construction should ensure cost effectiveness.
3. Simplicity: The devices should be easy to use by the visually impaired.
4. Availability of Components: The circuit was designed with readily available components.

5. Performance:

i. Should be able to identify an obstacle within a distance of 1m.
ii. Should operate when user is walking a maximum of 1m per second.
iii. Should find GPS signal within 1 minute of initialization.

6. Aesthetics:

i. Should weigh less than 1kg
ii. Main system should fit within a 2 x 0.5 x 0.5m in dimension

7. User-System Interface:

i. System should include modules rated at 5V.
ii. System should issue an audible warning when the obstacle is within 1m.

3.2 MATERIALS

A comprehensive list of the materials and their cost excluding technical and miscellaneous expenses is given in Table 3.1.

Table 3.1: Materials used in construction and their costs

`S/N	DEVICE	COST
1.	(3) Ultrasonic sensors (HC-Sr04)	N3,700
2.	Lidar sensor (TF mini)	N14,600
3.	Walking cane	N3,500
4.	Eye glasses	N1,100
5.	Vero Board	N500

6.	Microcontroller	N6,500
7.	5V DC Battery	N500
8.	MOSFETS	N500
9.	DC Vibration motor	N365
10.	Buzzer	N400
11.	Connecting Lead	N300
12.	Soldering Lead	N400
13.	Switch	N100
14.	Resistors	N500
15.	Packaging	N10,500
16.	Voltage Regulator	N200
17.	SMS/GPRS Module	N6,950

3.3 PROJECT DESIGN

The design is broken down into three units for ease of development. Each unit represents important aspects of the development process. One of the units represents the means of protection of the internal circuitry of the device. Others deal with the acquisition and processing of the signal.

i. Power Supply Unit Design
ii. Control Unit Design
iii. Packaging

3.3.1 POWER SUPPLY UNIT DESIGN AND IMPLEMENTATION

In the design of the power supply unit, a battery pack with two 9Vdc batteries is used to power the whole circuit. The voltage regulator (LM7805) is used to regulate the power supply voltage to about 5Vdc which is required by most components used in the system. The 9V dc batteries are used alongside the voltage regulator to power the microcontroller, buzzer, vibration motor, lidar sensor, GSM Module and three ultrasonic sensors which are current-consuming devices. This power supply unit is shown in Figure 3.3.

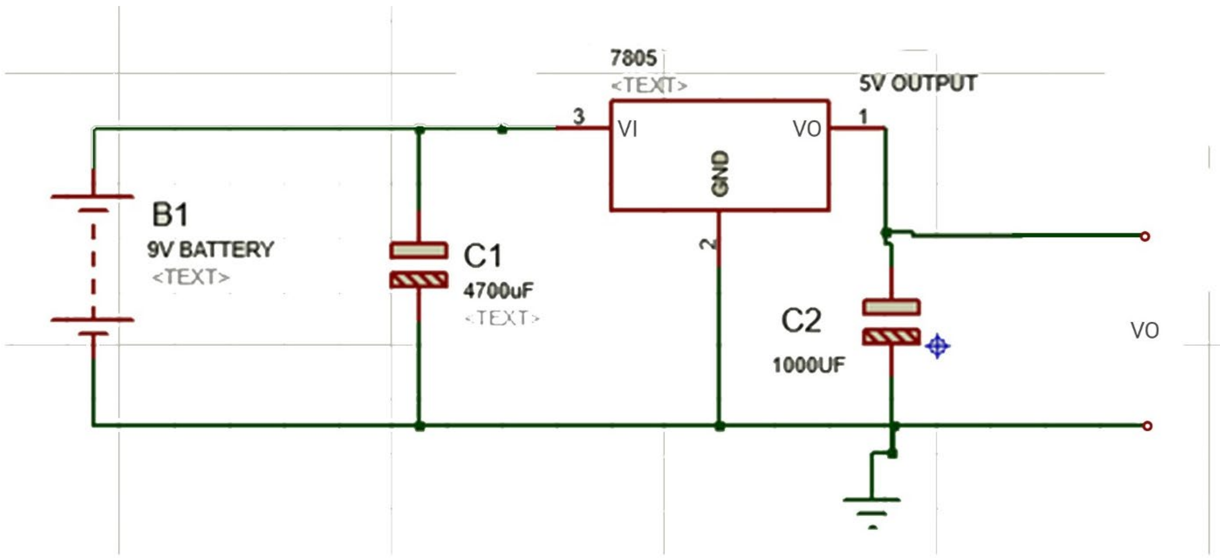

Figure 3.3: Schematic Diagram of the Power Supply Unit

Figure 3.3 shows the LM7805 IC used as a fixed output voltage regulator. Adding capacitors C1 and C2 between the voltage regulator is necessary to help improve the output voltage quality by reducing ripple when the load is varying. C1 is used to make slow changes in the input voltage given to the circuit to a steady form while C2 is used to make the slow changes in the output voltage from the regulator to the circuit to a steady form. When the value of these capacitors increases, stabilization is enlarged. Also, 100nF capacitors at the input and output are the minimum capacitances to prevent the voltage regulator from oscillating (Dreher,2016).

To determine the minimum amount of ceramic input capacitance required to reduce the ripple voltage amplitude to acceptable levels, we use Equation 3.1 (Texas Instruments, 2006).

$$C_{min} = \frac{I_{out} \times dc \times (1 - dc) \times 1000}{f_{sw} \times V_{P(max)}} \tag{3.1}$$

$$dc = \frac{V_{out}}{V_{in} \times \eta} \tag{3.2}$$

Where, η = Efficiency, f_{sw} is the switching frequency in kHz ,

I_{out} is the steady state output load current,

C_{min} is the minimum required ceramic input capacitance in μF.

$V_{P(max)}$ is the maximum allowed peak-peak ripple voltage (75 mVpp is recommended $V_{P(max)}$, which will yield approximately 22 mVrms of ripple voltage.),

dc is the duty cycle which is approximately the ratio of output to input dc voltage (Texas Instruments, 2006).

With 90% desired efficiency, regulated output voltage V_{in}, is the unregulated input voltage of 9V.

$$dc = \frac{V_{out}}{V_{in} \times \eta} = \frac{5}{9 \times 0.9} = 0.62$$

Since the required output current is 100mA, switching frequency is 67KHz and maximum allowable ripple is 75mV, so from Equation (3.1),

$$C_1 = \frac{100 \times 10^{-3} \times 0.62 \times (1 - 0.62) \times 1000}{67 \times 10^{3} \times 75 \times 10^{-3}} = 4689 \approx 4700 \mu F.$$

For the output capacitance,

$$\frac{C_1}{C_2} = 5 \tag{3.3}$$

Hence, $C_1 = \frac{4700\mu F}{5} = 940\mu F = 1000\mu F.$

Voltage Regulator (LM7805)

LM7805 is a voltage regulator integrated circuit. It is a member of the 78xx series of fixed linear voltage regulator ICs. The voltage source in a circuit may have fluctuations and would not give the fixed voltage output. The voltage regulator IC maintains the output voltage at constant value. The xx in 78XX indicates the fixed output voltage it is designed to provide. Hence the 7805 provides +5V regulated power supply. This particular voltage regulator requires a minimal value of 7.3V dc voltage to create a steady 5V d supply, about 2.3V more than what is expected at the output. Also, the input current required is always the same as the output current.

In the 7805 IC, the difference between the input and output voltage is dissipated as heat. Hence, the greater the difference between the input and output voltages, the greater the heat dissipation. Equation 3.3 gives the power generated as:

$$Power\ generated\ (Watt) = (Input\ voltage - 5V) \times output\ current \tag{3.4}$$

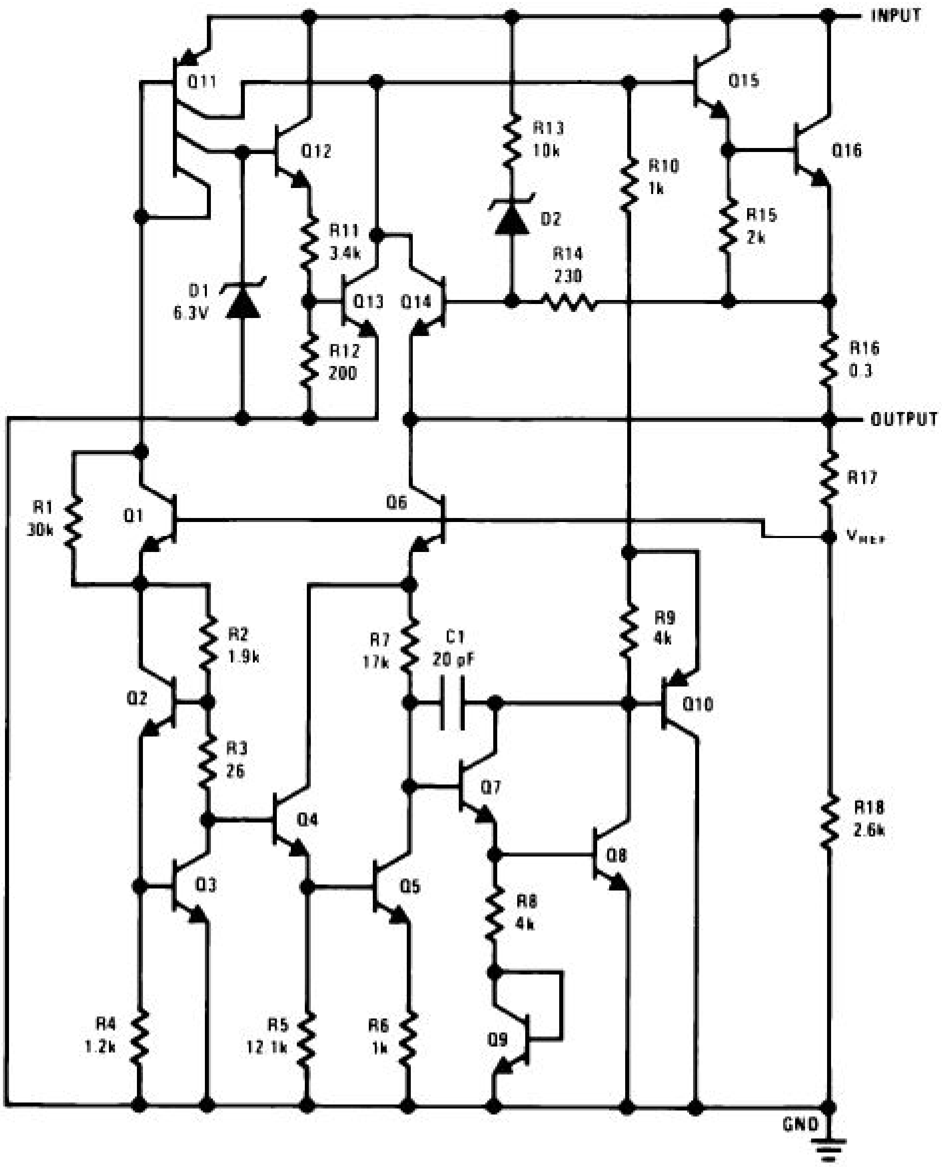

Figure 3.4: Schematic of the LM7805 voltage regulator IC (Texas Instruments, 2003)

3.3.2 CONTROL UNIT DESIGN

The control unit consist of the systems which guides the visually impaired user against obstacles and potholes in their path which make use of the Microcontroller, the Ultrasonic and Lidar detection systems, the GPS guiding systems along with the auditory and vibro-tactile alert systems using the buzzer and DC vibration motor respectively.

a. Microcontroller (AT328P)

The AT328P is a low-power, low-cost, high performance 8-bit microcontroller with 32K bytes of in-system programmable Flash memory. The on-chip Flash allows the program memory to be reprogrammed in-system or by a conventional non-volatile memory programmer.

By combining a versatile 8-bit CPU with in-system programmable flash on a monolithic chip, the Atmel AT328P is a powerful microcontroller which provides a highly-flexible and cost-effective solution to many embedded control applications.

The AT328P provides the following standard features: 32K bytes of Flash, 2K bytes of RAM, 23 I/O lines, programmable watch dog timer, two data pointers, three 16-bit timer/counters, a six-vector two-level interrupt architecture, a full duplex serial port, on-chip oscillator, and clock circuitry. In addition, the AT328P is designed with state logic for operation down to zero frequency and supports two software selectable power saving modes.

The Idle mode stops the CPU while allowing the RAM, timer/counter, serial port, and interrupt system to continue functioning. The Power-down mode saves the RAM contents but freezes the oscillator, disabling all other chip functions until the next interrupt or hardware reset.

Features

i. 32K Bytes of In-System Programmable (ISP) Flash memory with endurance of 10,000 Write/Erase Cycles

ii. External oscillator frequency of 0Hz to 20MHz for 4.5V to 5.5V Operating Range

iii. 8MHz internal calibrated internal oscillator

iv. 2K X 8-bit Internal RAM

v. 23 Programmable I/O Lines

vi. Three 16-bit Timer/ Counters

vii. Eight Interrupt Sources

viii. Operating current of 0.1µA Power-down Mode and 0.2mA Active Mode at 1MHz CPU speed, 1.8V and 25ºC

ix. Interrupt Recovery from Power-down Mode

x. Fast Programming Time (Components 101, 2019)

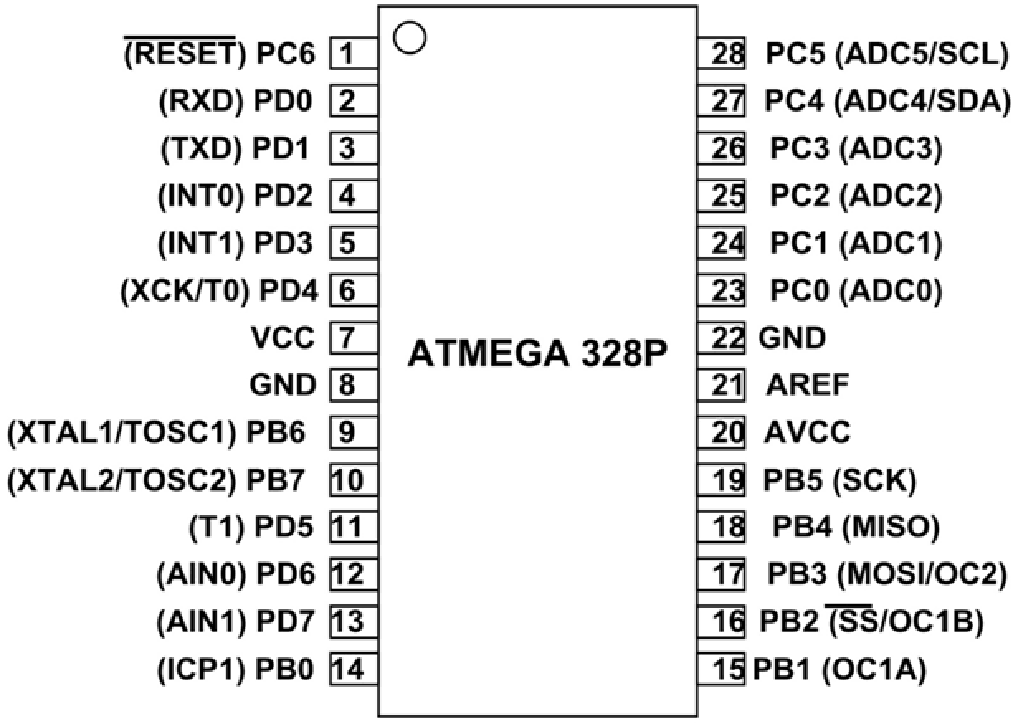

Figure 3.5: Atmel AT328P 28-pin PDIP Pinout Configuration

b. LiDAR Sensor (TF mini)

The TFmini is a mini LiDAR (Light Detection and Ranging) sensor module which is mainly capable of real-time contactless, accurate, stable and high-speed distance measurement. It is based on the Time of Flight (ToF) principle and measures the distance to a target by transmitting rapid pulses of Ultraviolet (UV), Visible or near Infrared (IR) laser light at – for example, 150,000 pulses per second to a surface through the transmitter (Kerry, Azo sensors, 2018).

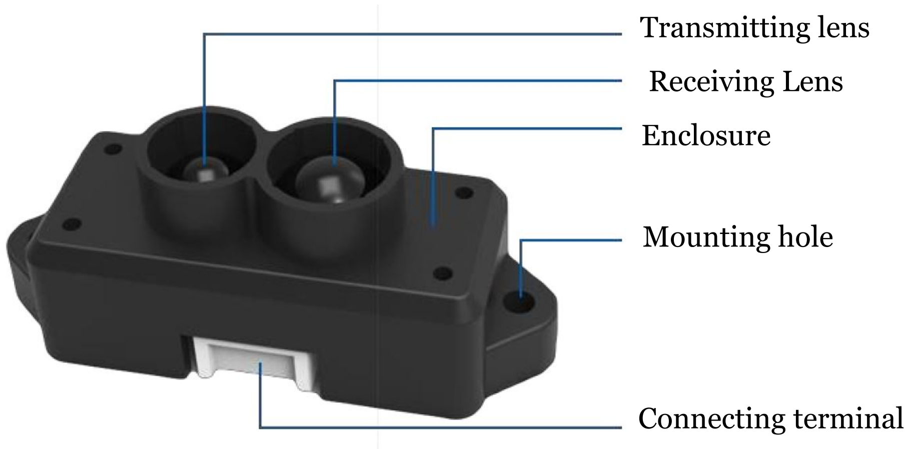

Figure 3.6: Labelled Picture of the TF Mini LiDAR sensor (User Manual, 2018)

When the light hits the target object, it is reflected back to the receiver which measures the time taken for the pulse to bounce back from the target.

The distance to the object is deduced by using the speed of light to calculate the distance travelled, as shown in Equation. 3.4 (User Manual, 2018).

$$D = \frac{c}{2} \cdot \frac{1}{2\pi f} \cdot \Delta\varphi \qquad (3.4)$$

Where D is the distance between the Lidar sensor and the object, C is the speed of light, f is the frequency of the electromagnetic wave and $\Delta\varphi$ the phase difference between the transmitted and received light signal, i.e.

$$\Delta\varphi = \varphi_1 - \varphi_2 \tag{3.5}$$

The Lidar sensor obtains its time of flight by measuring round-trip phase difference and then calculates relative range between the Lidar and the object or obstacle, as shown in Figure 3.7.

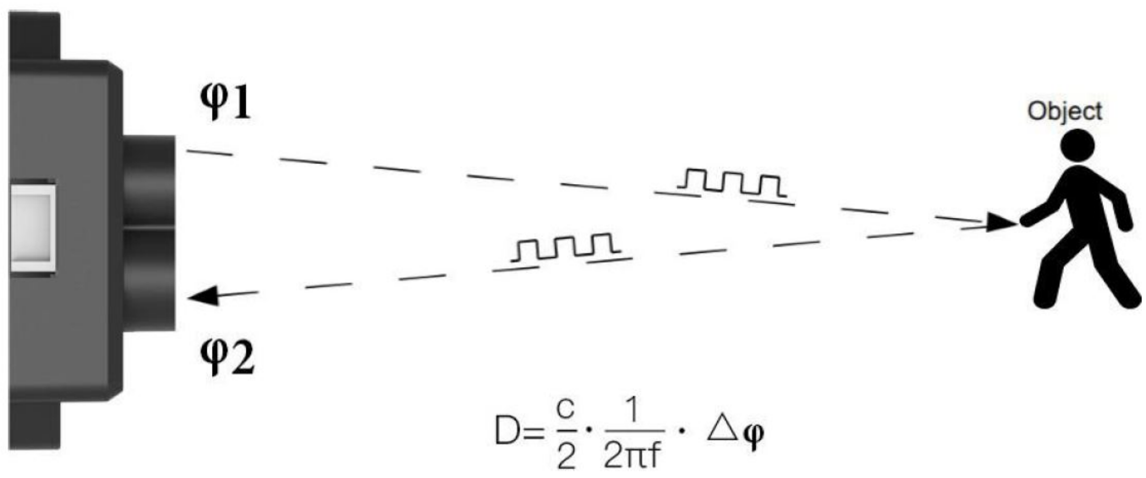

Figure 3.7: Working Principle of the Lidar sensor (User Manual, Accessed: January 2018).

System Modelling of the Lidar sensor on the Electronic Glasses

In this subsection, the operation of the lidar sensor is modelled to detect potholes and determine the approximate depth of the pothole.

Case 1: Light rays on Level Ground

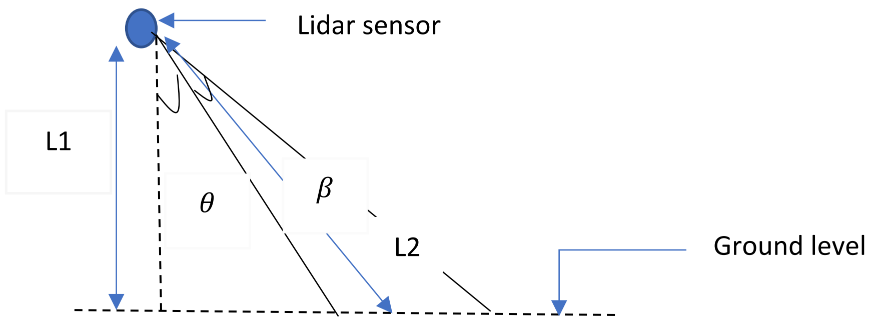

Figure 3.8: Light rays on Level Ground

Let the height of the impaired individual = L1

The Calibrated Height = L2

β (constant measuring angle of the lidar sensor) = 1.15° (TF-mini Lidar Manual: Accessed 2019),

θ = set angle between the Lidar sensor and the impaired individual

From Figure 3.8, since Detected height = Calibrated height = L2

Therefore, no pothole is detected.

Case 2: Light rays between Level Ground and pothole

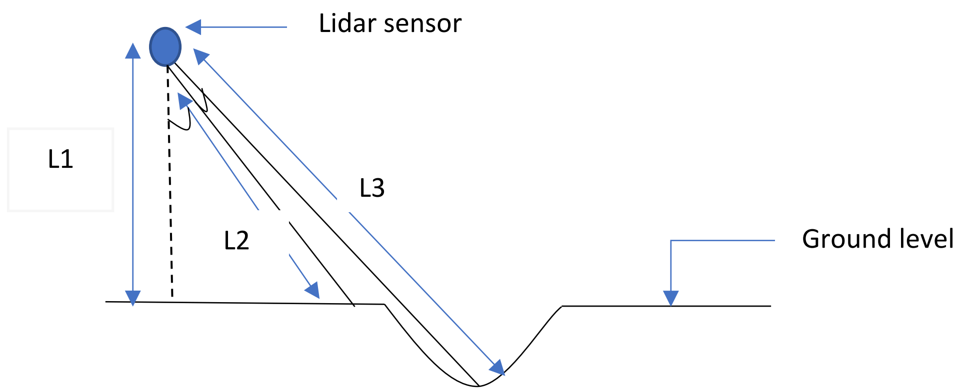

Figure 3.9: Light rays between Level Ground and pothole

From the Figure 3.9, Detected height ≠ Calibrated height,

Let Detected Height = L, then, L2 ≤ L ≤ L3

Calibrated height = L2

Hence since L > L2, then a pothole is detected.

Case 3: Light rays on Pothole

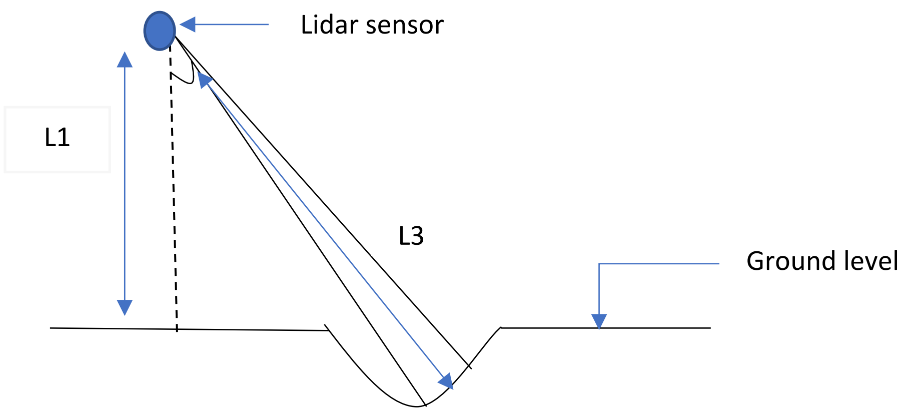

Figure 3.10: Light rays on Pothole

From Case 1, the Calibrated Height = L2

The detected height = L3,

Since L3 > L2, then the depth of the pothole = L3-L2 and pothole is detected.

c. Ultrasonic Sensor

The HC-Sr04 ultrasonic sensor transmits ultrasonic waves through the transmitter head and receives the ultrasonic waves reflected from an object through the receiver head. A supply of a short 10uS high level pulse at 15-degree angle is supplied to the trigger input to start the ranging, and then the module will send out an 8-cycle burst of ultrasound at 40kHz and raise its echo. The range is calculated through the time interval between the sending trigger signal and receiving echo signal. By measuring the length of time from the transmission to reception of the sonic wave, it detects the position of the obstacle. The formula to calculate the distance or position of the obstacle is given as:

$$Distance = \frac{\text{High level time} \times \text{Velocity of sound}}{2} \quad (3.6)$$

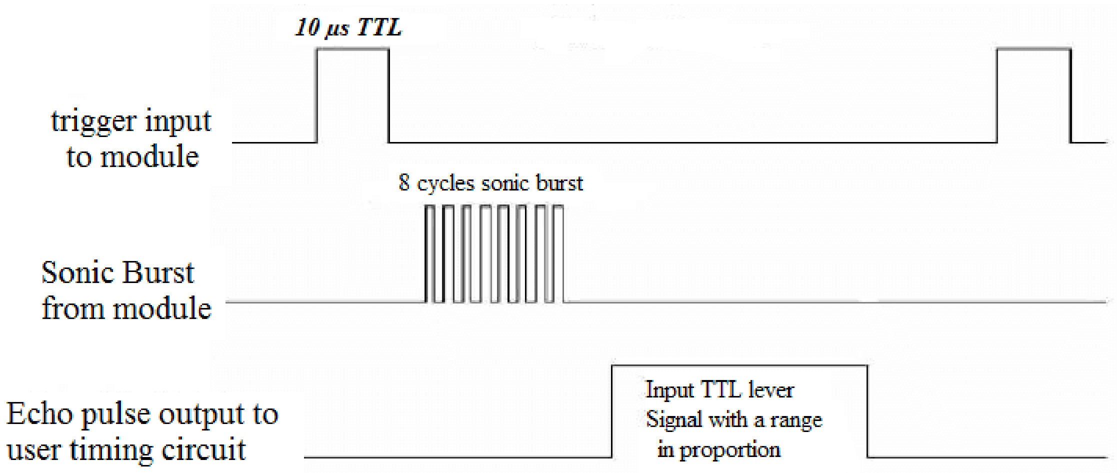

Figure 3.7: Timing Diagram of HC-Sr04 Ultrasonic sensor (Khayal, 2017)

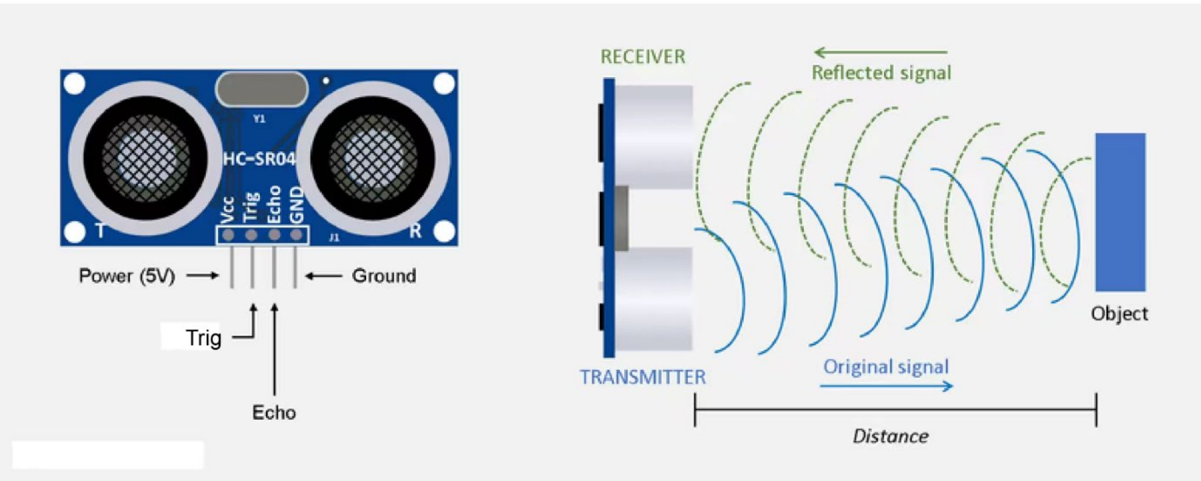

Figure 3.11: Schematic and Working Principle of Ultrasonic sensor (Osoyoo, 2018)

Sound Velocity in Atmosphere

The speed of sound is dependent on the medium through which the waves of sound travel. Sound travels slower in air in comparison to liquids and solids. The properties that have an effect on the speed of sound in air are pressure, density and molecular mass of the medium (Cheuk Wong,2000).

The velocity in the atmosphere is 331.5m/s at 0℃ and reaches 343m/s at room temperature of 20℃ , which can be calculated from the following formula:

$$Speed\ of\ Sound = 331.5m/s + 0.60m/s \times T(℃) \tag{3.7}$$

The HC-Sr04 used in this project provides 4cm – 100cm non-contact measurement function, with a ranging accuracy of up to 3mm.

System Modelling of the Ultrasonic sensor on the Electronic Guide Cane

The Ultrasonic sensor has the following characteristics;

Operating Voltage = 5V DC

Operating Current = 15mA

Operating frequency = 40kHz

400cm Maximum range and 2cm minimum range

Horizontal field of view (F.O.V) = 15º

Vertical field of view (F.O.V) = 4 º (Rigonz, 2014)

The Calibrated maximum distance in this work = 1m = 100cm

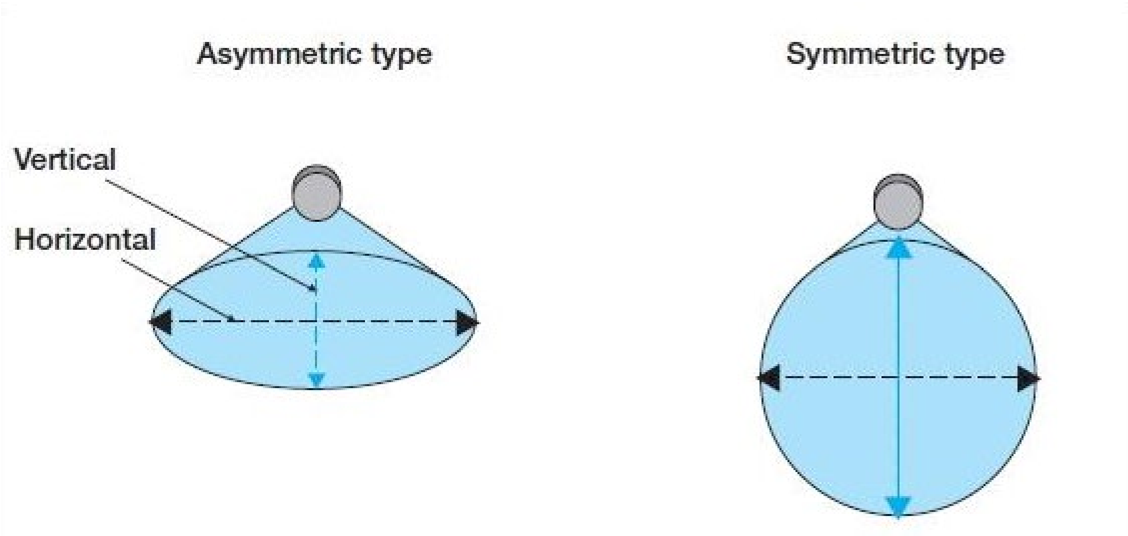

Figure 3.12: Directivity Type for Ultrasonic sensors (Newelectronics, 2010)

Hence, since the horizontal and vertical field of view are not equal for HC-SR04 ultrasonic sensors, then it has an asymmetric directivity.

To find the maximum horizontal coverage for the 3 ultrasonic sensors:

For a single ultrasonic sensor, we have the diagram below;

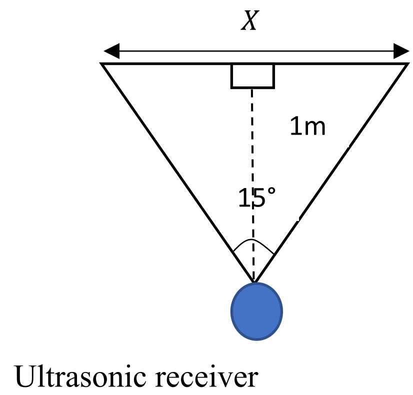

Figure 3.13: Schematic of the Ultrasonic receiver Field of View

By trigonometry, $X = 2(\tan(7.5) \times 1m)$ = 0.263m

Therefore, the maximum horizontal coverage for 3 ultrasonic sensors arranged vertically long the guide cane is 26.3cm.

To find the vertical horizontal coverage for the 3 ultrasonic sensors:

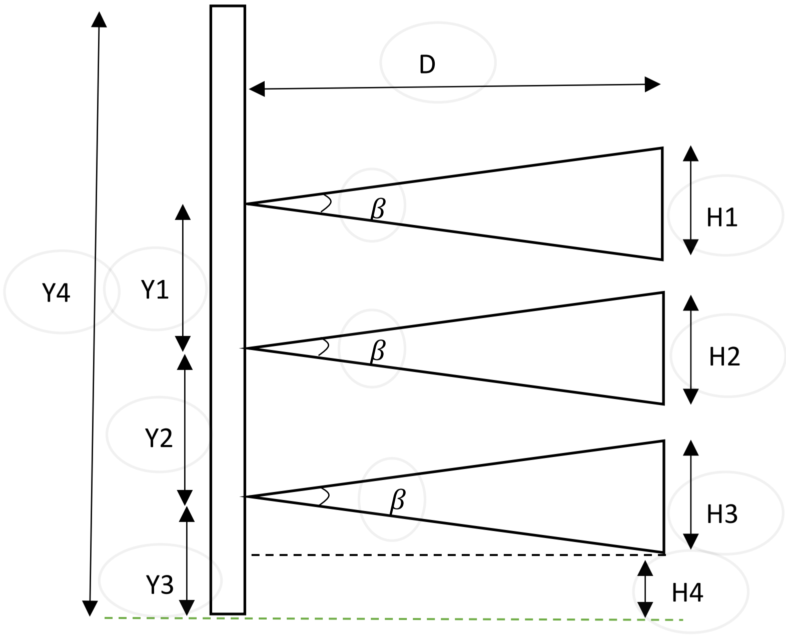

Figure 3.14: Schematic of the Ultrasonic receivers on the Electronic Guide Cane

Y1, Y2, and Y3 are the distances between the ultrasonic sensors, β is the vertical field of view angle, H1, H2 and H3 are the vertical coverage of the ultrasonic waves, H4 is the height from ground to avoid constant reflection of sound waves from the ground, while D is the calibrated distance by the ultrasonic sensor.

Y1= 24cm, Y2= 23cm, Y3= 17cm, and Y4= 120cm

Since we are using identical ultrasonic sensors, H1 = H2 = H3.

D =1m, β = 4°

By trigonometry, H1 $= 2(\tan(2°) \times 1m)$ = 0.07m = 7cm

Assuming the separation between H1, H2 and H3 to be negligible, Then the Maximum Vertical Coverage is 3 × H1= 0.21m

If Y3 is set at X(m), then the Minimum Height of Obstacle Detected is H4.

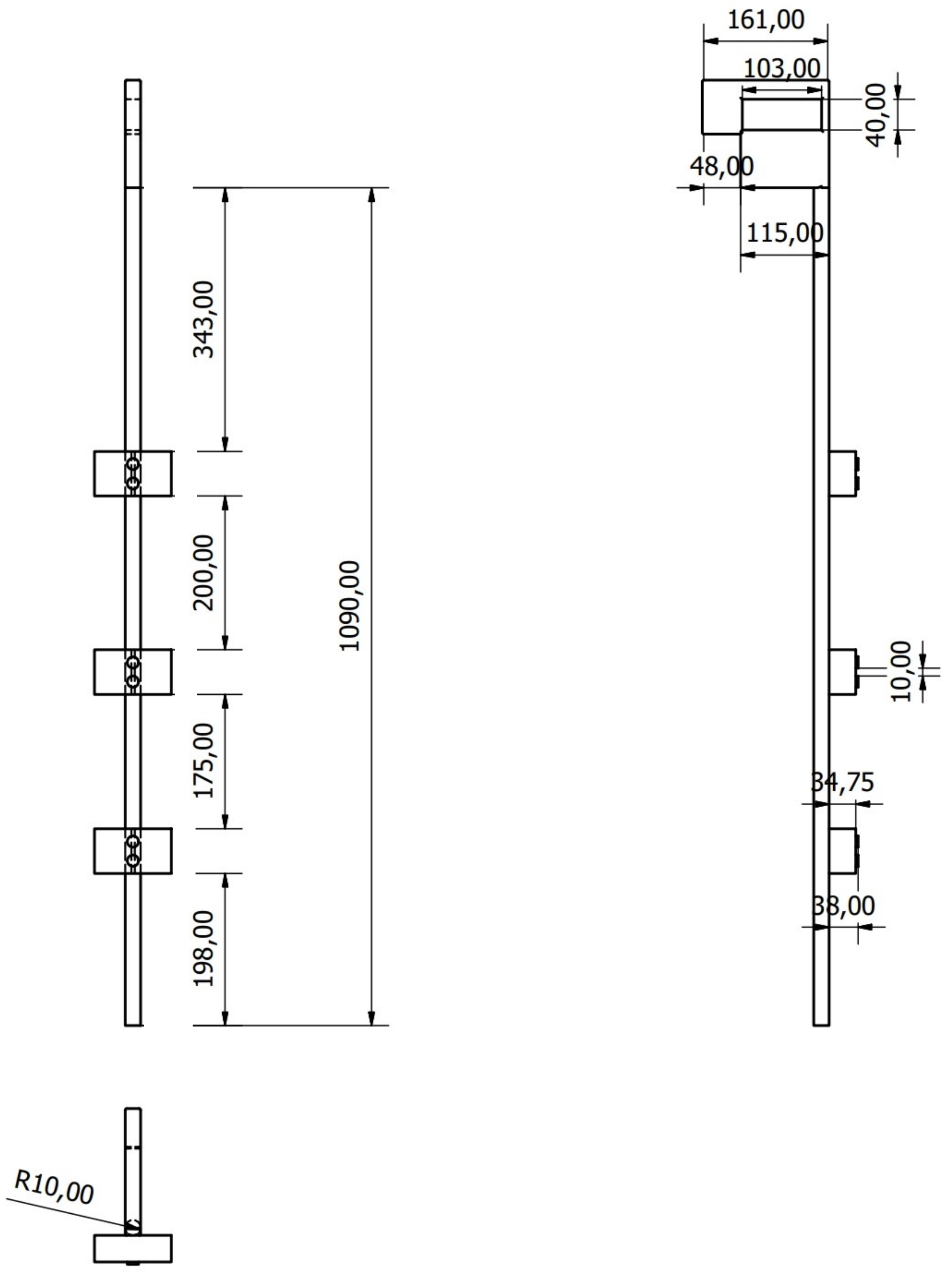

Figure 3.15: Engineering Drawing of the Obstacle Detection System in millimeters.

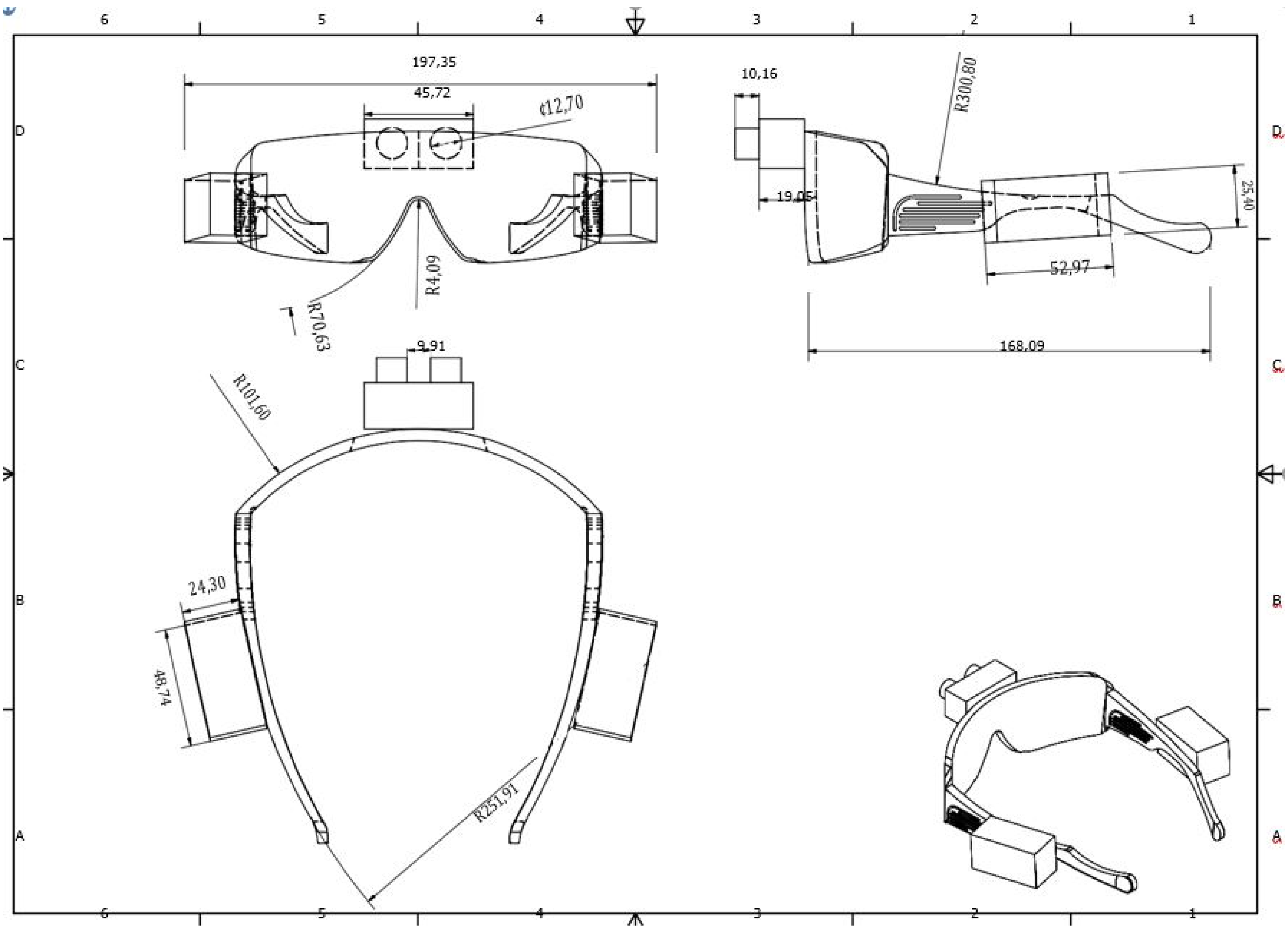

Figure 3.16: Engineering Drawing of the Electronic Glasses in millimeters.

d. Vibration Motor

The brushed coin vibration motor used in this work is made from a flat PCB on which the 3-pole commutation circuit is laid out around an internal shaft in the centre. The vibration motor consists of two 'voice coils' and a small mass that is integrated into flat plastic disc with a bearing in the middle, which sits on a shaft. Two brushes on the underside of the plastic disc make contact to the PCB commutation pads and provide power to the voice coils which generate magnetic field. This field interacts with the flux generated by a disc magnet that is attached to the motor chassis.

Figure 3.17: DC Coin Vibration Motor

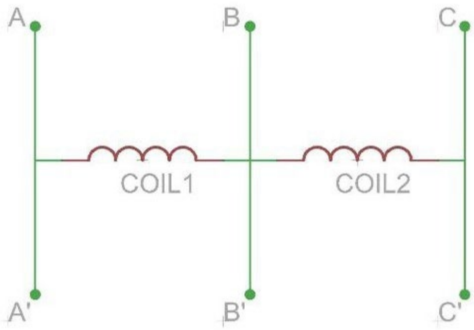

Figure 3.18: Coin vibration motor ciruit equivalent (Precision Micro Drives, Acessed: January 2019)

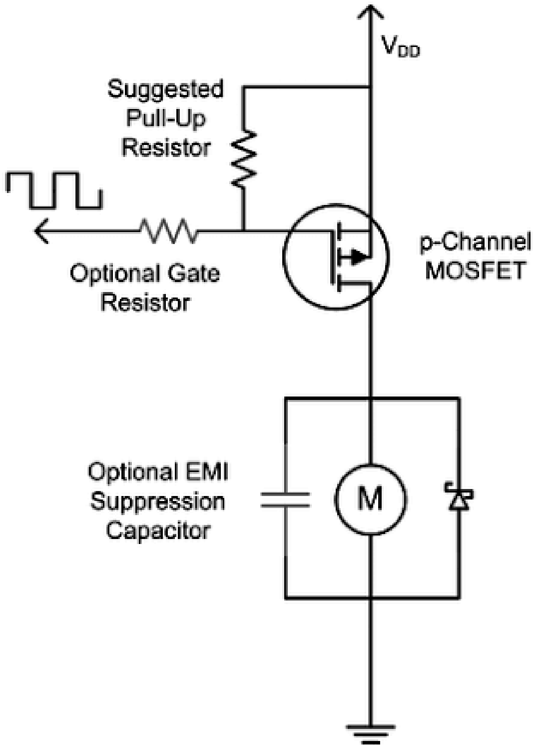

Figure 3.19: Connection circuit diagram of the coin vibration motor (Precision Micro Drives, Acessed: January 2019)

The commutation circuit alternates the direction of the field through the voice coils, and this interacts with the N-S pole pairs that are built into the neodymium magnet. The disc rotates, and due to the built-in off-centered eccentric mass, the motor vibrates.

Hence, whenever the ultrasonic sensor detects an obstacle, the microcontroller activates the vibration motor which responds in the process explained above.

e. Active Buzzer

The DC active buzzer used in this work is a piezo buzzer which is based on the inverse principle of piezoelectricity. Piezoelectricity is the phenomena of generating electricity when mechanical pressre is applied to certain materials, and the vice versa is also true. Piezoceramics are a class of man-made material, which poses piezoelectric effect and is used to make the disc in peizo buzzers (Engineers Garage, 2012).

Figure 3.20: DC Active buzzer

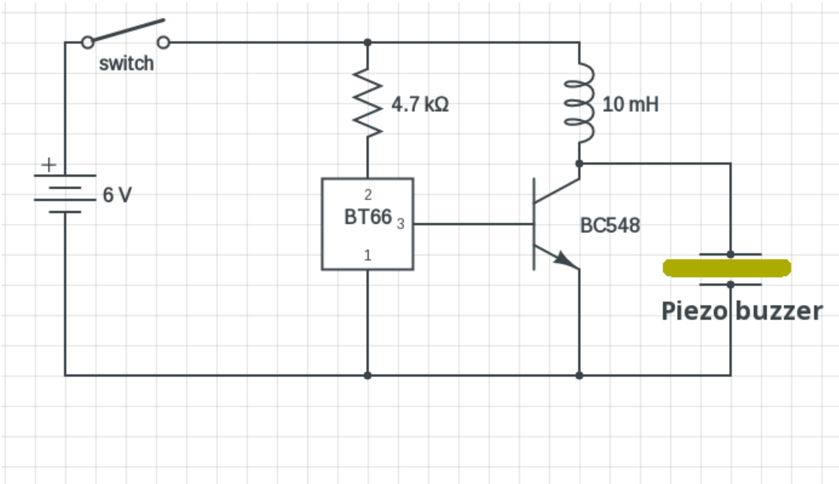

Figure 3.21: Circuit Diagram of the piezo buzzer (Circuits DIY, Accessed: January 2019)

When a small DC Voltage is applied to the input pins, it is first converted to an oscillating signal using the combination of a resistor and a transistor. These oscillating signals are amplified using the inductor coil. When high voltage alternating signals are applied to the piezo ceramic disc, it causes the metal plate to bend in opposite direction. When the metal plate bends and shrink continuously, it produces sound waves in the air.

f. GSM/GPRS MODULE

The GSM/GPRS module is used to establish communication between a computer and a GSM-GPRS system. Global System for Mobile communication (GSM) is an architecture used for mobile communication in most of the countries. Global Packet Radio Service (GPRS) is an extension of GSM that enables higher data transmission rate.

Figure 3.22 : GSM/GPRS M590 Module

The GSM/GPRS module assembles a GSM/GPRS modem with standard communication interfaces like RS-232 (Serial Port) so that it can be easily interfaced with the AT89S52 microcontroller based system. The voltage regulator supplies the 5V power supply required by the circuit from the 9V DC battery.

3.3.3 PACKAGING

The casing on the walking aid is made of plastic which houses the microcontroller, ultrasonic sensors, the DC vibrator and all other elecronic components integrated on the veroboard to keep the components safe from physical or electrical damage.While the lidar sensor is mounted on the polarized eye glass.

Plate 3.1: Packaging of the Guide glasses.

Plate 3.2: Packaging of the Electronic Guide Cane.

3.4 HARDWARE CONNECTION

The terminals of all the components used were soldered together using the soldering lead and a soldering iron on the veroboard to ensure firm contact after each sub-system test was carried out using a multi-meter.

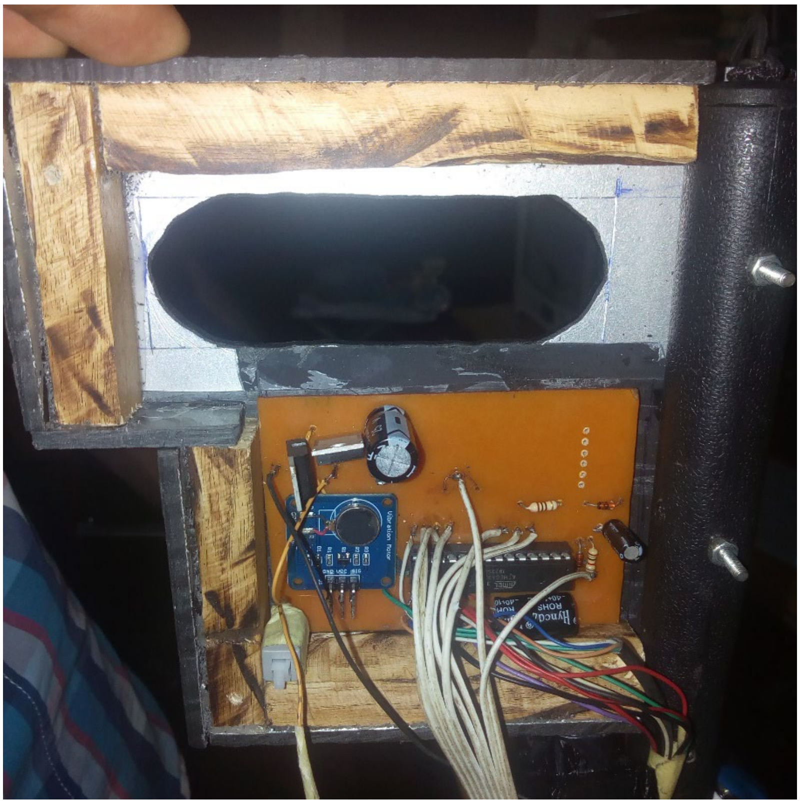

Plate 3.3: Hardware connection of the Electronic walking aid.

3.5 SOFTWARE IMPLEMENTATION

Programming of the Microcontroller

In this work, the assembly language was used on the KEIL MICROVERSION software. The flow chart of the software program is shown below while the code used can be referred to in Appendix A.

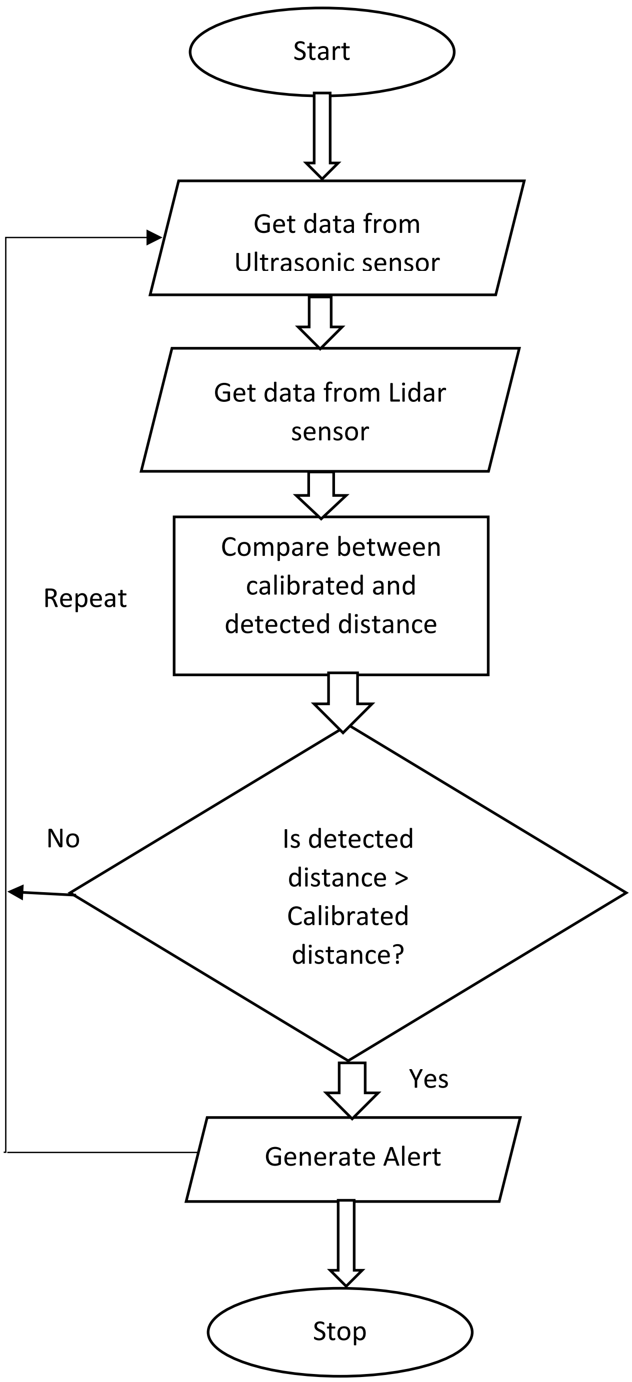

Figure 3.22: Flow Chart of the Microcontroller software program.

3.6 WORKING PRINCIPLE OF THE MULTIDIMENSIONAL ELECTRONIC TRAVEL AID

The Electronic travel aid is designed to provide navigation as well as obstacle and pothole detection to the visually impaired. It consists of three major parts:

a) Obstacle Detection System

b) Pothole Detection System

c) Navigation System

3.6.1 OBSTACLE DETECTION SYSTEM

The Electronic Cane is built as an advanced form of the conventional waking cane for to provide feedback to the visually impaired user against obstacles and potholes in addition to mechanically detecting obstacles in the path of the user.

Three Ultrasonic sensors are placed 20cm apart on the conventional white cane which send signals of detected obstacles to the AT89S52 microcontroller. The Microcontroller activates the Vibration motor at the handle of the Electronic cane as a vibro-tactile alert system to the blind user. The SMS Module is used to alert the user's caretaker of the location of the visually impaired user when a button is pressed.

3.6.2 POTHOLE DETECTION SYSTEM

The Pothole detection system consist of the lidar sensor, microcontroller and the battery mounted on an eye glass. The Lidar sensor is calibrated to detect potholes within 5metres from the user's eye at an angle of 30 to 45 degrees, and alert the user when there is more than 10cm change in the ground level through a buzzer, indicating that a pothole in the user's path.

The above-mentioned components connection and their inter-relationship makes up the eventual circuit diagram for the electronic travel aid system which is shown in Figure 3.23.

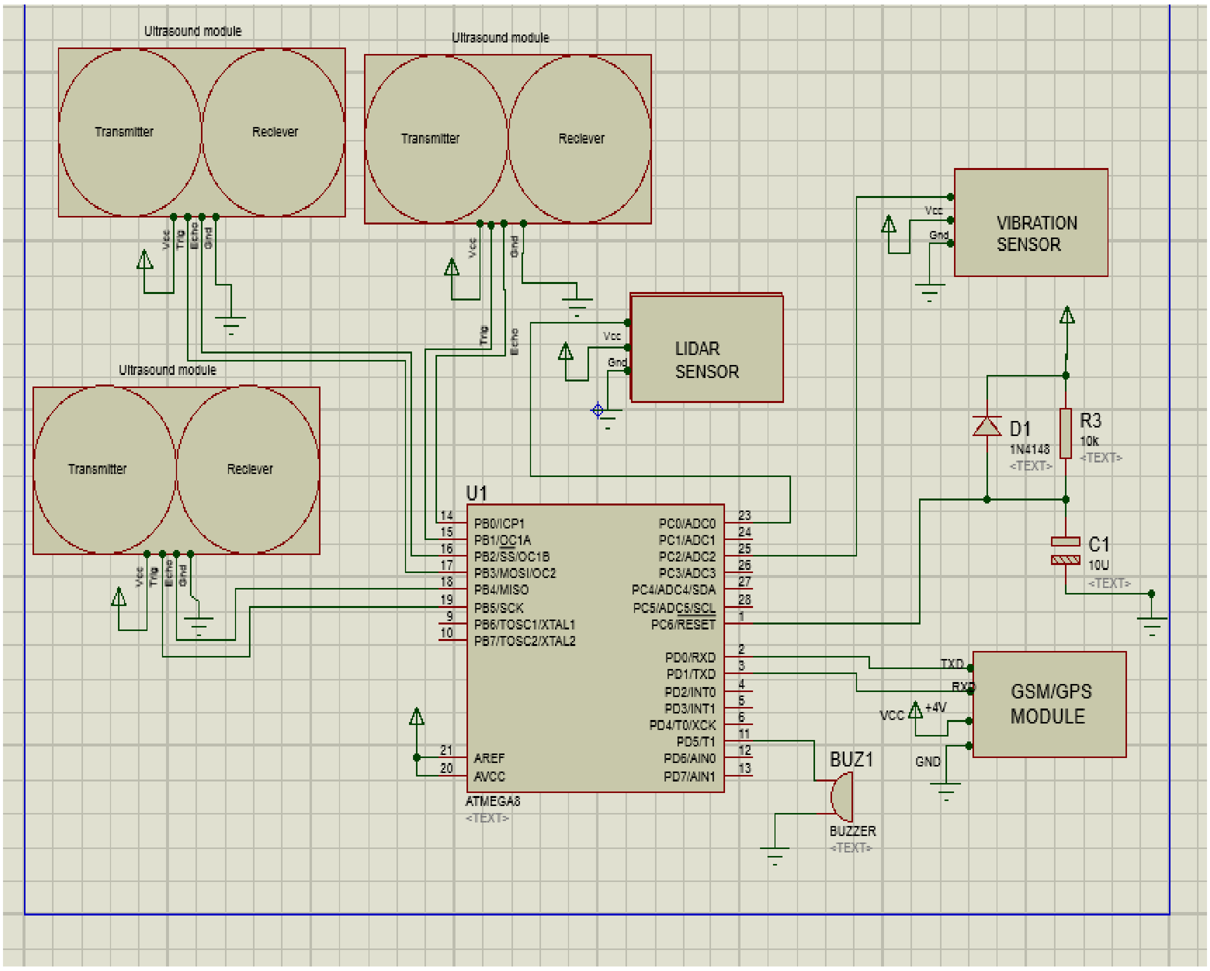

Figure 3.23: Circuit diagram of the Electronic Travel Aid system

3.6.3 NAVIGATION SYSTEM

We interface this work with an existing Android application which uses GPS and Google voice to guide the blind users to their destination. The user speaks to google voice on the android phone which provides the direction that the user needs.

CHAPTER FOUR

TESTING AND RESULTS

4.0 INTRODUCTION

The testing of the project design and the results obtained is discussed in this chapter. This is carried out by observing the performance of the walking aid when used on blind folded and visually impaired individual and taking the corresponding result.

4.1 TESTING

The Electronic Travel Aid system after complete design was put to test by placing obstacles in the paths of the user at varying distances as shown in Plates 4.1 to Plates 4.5. The test was carried out on the three different systems which are:

a) The Obstacle detection System

b) The Pothole detection System

c) The Navigation System

4.1.1 OBSTACLE DETECTION SYSTEM

The obstacle detection system was carried out to test the response of the Electronic Guide cane on visually impaired and blind folded individuals. This is shown in Plate 4.1

Plate 4.1: Obstacle detection measurement

4.1.2 POTHOLE DETECTION SYSTEM

The pothole detection system was tested on potholes of different depths to determine the effective detection as shown in Plate 4.2.

Plate 4.2: Pothole detection

4.1.3 NAVIGATION SYSTEM

The Navigation system was tested on blind folded individuals with an existing Android application which uses GPS and Google voice to guide the blind users to their destination. The user speaks to google voice on the android phone which provides the direction that the user needs.

4.2 RESULTS

The result of this work will feature the performance analysis of the navigation, obstacle and pothole detection system which consists of the accuracy, energy cost, and ease of use with existing systems.

Table 4.1: Consumption of Battery Voltage with Time

S/N	Battery Voltage (volts)	Time Interval (mins)
1	9.74	0
2	9.3	2
3	9.18	2
4	8.88	2
5	8.73	2
6	8.61	2

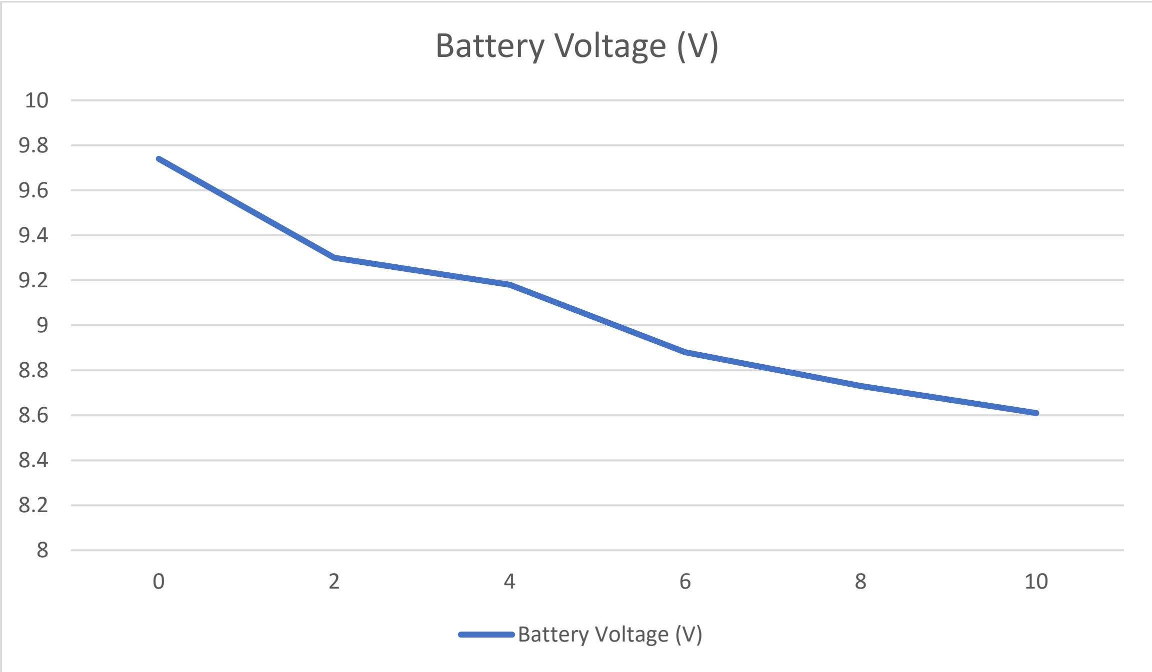

Figure 4.1: Graph of Battery voltage drop with Time

Table 4.2: Table of Objects detected

S/N	Object distance (m)	Detected
1	0.2	Yes
2	0.4	Yes
3	0.6	Yes
4	0.8	Yes
5	1.0	Varying

6	1.1	No
7	1.2	No
8	1.4	No

4.3 CHALLENGES

The following challenges were encountered in the process of constructing the multidimensional blind man walking cane.

1. The procurement of the required materials, especially the Lidar sensor was time consuming since it was scarce, hence we imported it.
2. We experienced short circuits frequently due to initial improper measurements and soldering errors, but they were finally resolved.
3. Syntax errors while programming the microcontroller occurred regularly, and calibration of the sensors with the microcontroller for accurate detection was demanding.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

In the beginning, the aim of this project is to develop an effective and efficient navigation system for the visually impaired. This work was carried out by analysing the existing walking aids and navigation systems, and coming up with our own idea to make a better aid.

The proposed walking aid and navigation system worked perfectly and was proven to high efficiency based on power consumption, ease of use, cost and weight.

5.2 RECOMMENDATION

The continuous advancement in detection and navigation systems provides a plethora of methods for guiding visually impaired users more accurately.

Although the development of the multi-dimensional walking aid and navigation system based connotes a suitable method to guide visually impaired user to their destination, there is room for improvement in the aspect of guiding visually impaired users using the following:

1. Instead of using conventional DC batteries, solar charged batteries can be used to make it Eco-friendly. This gives an added advantage to the user, such that the visually impaired user need not worry about charging it, since it is automated.
2. LiDAR sensors can also be placed on the guide cane, to detect potholes as well, in case the visually impaired user faces another direction.

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APPENDIX

The Assembly code is given below;

```
.EQU    PORTC  = 0X08
.EQU    DDRC   = 0X07
.EQU    PINC   = 0X06
.EQU    PORTB  = 0X05
.EQU    DDRB   = 0X04
.EQU    PINB   = 0X03
.EQU    PORTD  = 0X0B
.EQU    DDRD   = 0X0A
.EQU    PIND   = 0X09
.EQU    SPH             = 0X3E
.EQU    SPL             = 0X3D
.EQU    MCUCR                   = 0X35
.EQU    TIFR0  = 0X15
.EQU    TCCR0A          = 0X24
.EQU    TCCR0B          = 0X25
.EQU    TCNT0  =        0X26
.EQU    OCR0A  =        0X27
.EQU    OCR0B  =        0X28
.EQU    TIMSK0          = 0X6E
.EQU    EEARH  = 0X22
.EQU    EEARL  = 0X21
.EQU    EEDR   = 0X20
.EQU    EECR   = 0X1F
.EQU    TIFR2  = 0X17
.EQU    TCCR2A          = 0XB0
.EQU    TCCR2B          = 0XB1
.EQU    TCNT2  =        0XB2
.EQU    OCR2A  =        0XB3
.EQU    OCR2B  =        0XB4
.EQU    TIMSK2          = 0X70
.EQU    TIFR1  = 0X16
.EQU    TCCR1A          = 0X80
.EQU    TCCR1B          = 0X81
.EQU    TCCR1C          = 0X82
.EQU    TCNT1L          =       0X84
.EQU    TCNT1H          =       0X85
.EQU    OCR1AL          =       0X88
.EQU    OCR1AH          =       0X89
.EQU    OCR1BL          =       0X8A
.EQU    OCR1BH          =       0X8B
.EQU    TIMSK1          = 0X6F
.EQU    SREG   = 0X3F
.EQU    UDR0   = 0XC6
.EQU    UBRR0H          = 0XC5
.EQU    UBRR0L          = 0XC4
.EQU    UCSR0C          = 0XC2
.EQU    UCSR0B          = 0XC1
.EQU    UCSR0A          = 0XC0
.EQU    ADCH   = 0X79
.EQU    ADCL   = 0X78
.EQU    ADCSRA          = 0X7A
.EQU    ADCSRB          = 0X7B
.EQU    ADMUX           = 0X7C
.EQU    DIDR0  = 0X7E
.EQU    OSCCAL          = 0X66
.EQU    RESULT1         = 0X100
.EQU    RESULT2         = 0X101
.EQU    DRESULT1 = 0X102
.EQU    DRESULT2 = 0X103
.EQU    V1     = 0X104
.EQU    V2 = 0X105
.EQU    V3 = 0X106
.ORG    0X00
START:
```

```
        LDI     R17,0X5F
        OUT     SPL,R17
        LDI     R17,0X04
        OUT     SPH,R17
        CLR     R17  ; CLEARED R17
        OUT     PORTD,R17  ; SENT TO PORTD
        LDI     R17,0XFC ; LOADED FF INTO R17
        OUT     DDRD,R17    ; SENT IT TO DIRECTION REG
        CLR     R17  ; CLEARED R17
        OUT     PORTC,R17  ; SENT TO PORTC
        LDI     R17,0XFF ; LOADED FF INTO R17
        OUT     DDRC,R17    ; SENT IT TO DIRECTION REG
        LDI     R17,0X04  ;
        OUT     PORTB,R17  ; SENT TO PORTB
        LDI     R17,0XD5 ; LOADED D5 INTO R17     11010101
        OUT     DDRB,R17    ; SENT IT TO DIRECTION REG
        RCALL INTLCD
        RCALL DSP1   ;WALKING STICK TO DISPLAY
        RCALL DELAY1SEC
        RCALL CLRSCREEN
REDO:
        RCALL ULTRASOUND  ; RETURNS A VALUE IN R11 AND R12 IN UNITS OF 0.25 CM
        STS     RESULT1,R11
        STS     RESULT2,R12
        RCALL BINTODEC
        LDI     R16,0X40
        RCALL RSLOW
        LDS     R16,DRESULT2
        ORI     R16,0X30
        RCALL RSHIGH
        LDS     R16,DRESULT1
        ORI     R16,0X30
        RCALL RSHIGH
        LDS     R16,RESULT1
        ORI     R16,0X30
        RCALL RSHIGH
        RCALL BUZZER
        RCALL XULTRASOUND
        STS     RESULT1,R11
        STS     RESULT2,R12
        RCALL BINTODEC
        LDI     R16,0X48
        RCALL RSLOW
        LDS     R16,DRESULT2
        ORI     R16,0X30
        RCALL RSHIGH
        LDS     R16,DRESULT1
        ORI     R16,0X30
        RCALL RSHIGH
        LDS     R16,RESULT1
        ORI     R16,0X30
        RCALL RSHIGH
        RCALL BUZZER
        RCALL YULTRASOUND
        STS     RESULT1,R11
        STS     RESULT2,R12
        RCALL BINTODEC
        LDI     R16,0X00
        RCALL RSLOW
        LDS     R16,DRESULT2
        ORI     R16,0X30
        RCALL RSHIGH
        LDS     R16,DRESULT1
        ORI     R16,0X30
        RCALL RSHIGH
        LDS     R16,RESULT1
        ORI     R16,0X30
```

```
        RCALL RSHIGH
        RCALL BUZZER
        RJMP  REDO
BUZZER:
;BUZZER
        ;CHECK IF R12 IS 0 IF YES PROCEED
ELSE EXIT
        MOV   R17,R12
        CPI   R17,0X00
        BREQ  BUZZER2
        LDI   R17,0X00
        OUT   PORTC,R17
        RET
BUZZER2:        ;CHECK IF R11 IS 77 OR
BELOW IF YES PROCEED ELSE EXIT
        MOV   R17,R11
;       CPI   R17,0X78
;       BRSH  BUZZER4
        LDI   R17,0XFF  ;00111000
        OUT   PORTC,R17
        RCALL DELAY100MS
        RCALL DELAY100MS
        LDI   R17,0X00  ;00000000
        OUT   PORTC,R17
        RCALL DELAY100MS
        RCALL DELAY100MS
BUZZER4:
        LDI   R17,0X00
        OUT   PORTC,R17
        RET
ULTRASOUND:   ; R13 R14 HOLD VALUES
TEMPORARY
        SBI   PORTB,0
        CLR   R13
        CLR   R14
        CLR   R11
        CLR   R12
        CLR   R16
        CLR   R17
        RCALL DELAY1MS
        RCALL DELAY1MS
        RCALL DELAY1MS
        RCALL DELAY1MS
        RCALL DELAY1MS
ULTRASOUNDB:
        RCALL DELAY1MS
        RCALL DELAY1MS
        RCALL DELAY1MS
        RCALL DELAY1MS
        RCALL DELAY1MS
        CLR   R18
        CBI   PORTB,0
ULTRASOUNDC:
        SBIC  PINB,1
        RJMP  ULTRACOUNTX
        INC   R18
        RCALL DELAY1US
        RCALL DELAY1US
        CPSE  R18,R11
        RJMP  ULTRASOUNDC
        RJMP  ULTRASOUND
ULTRACOUNTX:
        SBI   PORTB,0
ULTRACOUNT:  ;CHECK TIMING
        INC   R16
        CPSE  R16,R11
        RJMP  ULTRACOUNT2
        INC   R17
        SBRC  R17,2
        RJMP  ULTRACOUNTXX   ; TO THIS
POINT TO ADJUST DELAY15US
        RJMP  ULTRACOUNT2
ULTRACOUNT2A:
```

```
        NOP
        NOP
        NOP
        NOP
        NOP
        NOP
ULTRACOUNT2:
        RCALL DELAY15US ;COMPENSATED
        SBIC    PINB,1
        RJMP    ULTRACOUNT
ULTRACOUNT3:
        INC     R12
        SBRS    R12,3
        RJMP    ULTRASOUNDBX
        ADD     R13,R16
        ADC     R14,R17
        CLC
        ROR     R14
        ROR     R13
        CLC
        ROR     R14
        ROR     R13
        CLC
        ROR     R14
        ROR     R13
        MOV     R11,R13
        MOV     R12,R14
        RET
ULTRASOUNDBX:
        ADD     R13,R16
        ADC     R14,R17
        CLR     R16
        CLR     R17
        RJMP    ULTRASOUNDB
ULTRACOUNTXX:
        SBIC    PINB,1
        RJMP    ULTRACOUNTXX
        RJMP    ULTRACOUNT3
XULTRASOUND:   ; R13 R14 HOLD VALUES
TEMPORARY
        SBI     PORTB,2
        CLR     R13
        CLR     R14
        CLR     R11
        CLR     R12
        CLR     R16
        CLR     R17
        RCALL DELAY1MS
        RCALL DELAY1MS
        RCALL DELAY1MS
        RCALL DELAY1MS
        RCALL DELAY1MS
XULTRASOUNDB:
        RCALL DELAY1MS
        RCALL DELAY1MS
        RCALL DELAY1MS
        RCALL DELAY1MS
        RCALL DELAY1MS
        CLR     R18
        CBI     PORTB,2
XULTRASOUNDC:
        SBIC    PINB,3
        RJMP    XULTRACOUNTX
        INC     R18
        RCALL DELAY1US
        RCALL DELAY1US
        CPSE    R18,R11
        RJMP    XULTRASOUNDC
        RJMP    XULTRASOUND
XULTRACOUNTX:
        SBI     PORTB,2
XULTRACOUNT:  ;CHECK TIMING
```

```
        INC     R16
        CPSE    R16,R11
        RJMP    XULTRACOUNT2
        INC     R17
        SBRC    R17,2
        RJMP    XULTRACOUNTXX  ; TO THIS
POINT TO ADJUST DELAY15US
        RJMP    XULTRACOUNT2
XULTRACOUNT2A:
        NOP
        NOP
        NOP
        NOP
        NOP
        NOP
XULTRACOUNT2:
        RCALL DELAY15US ;COMPENSATED
        SBIC    PINB,3
        RJMP    XULTRACOUNT
XULTRACOUNT3:
        INC     R12
        SBRS    R12,3
        RJMP    XULTRASOUNDBX
        ADD     R13,R16
        ADC     R14,R17
        CLC
        ROR     R14
        ROR     R13
        CLC
        ROR     R14
        ROR     R13
        CLC
        ROR     R14
        ROR     R13
        MOV     R11,R13
        MOV     R12,R14
        RET
XULTRASOUNDBX:
        ADD     R13,R16
        ADC     R14,R17
        CLR     R16
        CLR     R17
        RJMP    XULTRASOUND
XULTRACOUNTXX:
        SBIC    PINB,3
        RJMP    XULTRACOUNTXX
        RJMP    XULTRACOUNT3
YULTRASOUND:  ; R13 R14 HOLD VALUES
TEMPORARY
        SBI     PORTB,4
        CLR     R13
        CLR     R14
        CLR     R11
        CLR     R12
        CLR     R16
        CLR     R17
        RCALL DELAY1MS
        RCALL DELAY1MS
        RCALL DELAY1MS
        RCALL DELAY1MS
        RCALL DELAY1MS
YULTRASOUNDB:
        RCALL DELAY1MS
        RCALL DELAY1MS
        RCALL DELAY1MS
        RCALL DELAY1MS
        RCALL DELAY1MS
        CLR     R18
        CBI     PORTB,4
YULTRASOUNDC:
        SBIC    PINB,5
        RJMP    YULTRACOUNTX
```

```
	INC	R18
	RCALL	DELAY1US
	RCALL	DELAY1US
	CPSE	R18,R11
	RJMP	YULTRASOUNDC
	RJMP	YULTRASOUND

YULTRACOUNTX:
	SBI	PORTB,4
YULTRACOUNT:  ;CHECK TIMING
	INC	R16
	CPSE	R16,R11
	RJMP	YULTRACOUNT2
	INC	R17
	SBRC	R17,2
	RJMP	YULTRACOUNTXX  ; TO THIS
POINT TO ADJUST DELAY15US
	RJMP	YULTRACOUNT2
YULTRACOUNT2A:
	NOP
	NOP
	NOP
	NOP
	NOP
	NOP
YULTRACOUNT2:
	RCALL	DELAY15US ;COMPENSATED
	SBIC	PINB,5
	RJMP	YULTRACOUNT
YULTRACOUNT3:
	INC	R12
	SBRS	R12,3
	RJMP	YULTRASOUNDBX
	ADD	R13,R16
	ADC	R14,R17
	CLC
	ROR	R14
	ROR	R13
	CLC
	ROR	R14
	ROR	R13
	CLC
	ROR	R14
	ROR	R13
	MOV	R11,R13
	MOV	R12,R14
	RET
YULTRASOUNDBX:
	ADD	R13,R16
	ADC	R14,R17
	CLR	R16
	CLR	R17
	RJMP	YULTRASOUNDB

YULTRACOUNTXX:
	SBIC	PINB,5
	RJMP	YULTRACOUNTXX
	RJMP	YULTRACOUNT3
DSP1: ; TO DISPLAY
	LDI	R16,0X05
	RCALL	RSLOW
	LDI	R16,0X4D
	RCALL	RSHIGH
	LDI	R16,0X6F
	RCALL	RSHIGH
	LDI	R16,0X64
	RCALL	RSHIGH
	LDI	R16,0X75
	RCALL	RSHIGH
	LDI	R16,0X6C
	RCALL	RSHIGH
	LDI	R16,0X65
```

```
        RCALL RSHIGH
        RET
;THESE DELAYS DO NOT USE TIMERS AND INTERRUPT
;ADJUST AS NEEDED FOR OTHER CRYSTALS
; FOR 16MHZ ADD 8 NOPS TO EACH INCIDENT OF 1 NOP  OR CREATE A SUB AND PUT 1 NOP
;FOR 20MHZ  ADD 12 NOPS TO EACH INCIDENT OF 1 NOP OR CREATE A SUB AND PUT 5 NOP
SUB16:
        NOP
        RET
SUB20:
        NOP
        NOP
        NOP
        NOP
        NOP
        RET
;THERE ARE 8 INCIDENCE OF RCALL SUB16/20 IF THE NEED ARISES FOR ADJUSTMENT
DELAY1US:   ; IF 8MHZ THEN EACH NOP IS 0.125US REQUIRES 8 NOPS TO MAKE 1US
        NOP    ; RET = 4 , RCALL = 3 HENCE ONLY ONE NOP NEEDED
        ;RCALL SUB16
        ;RCALL SUB20
        RET
DELAY10US: ; CALLS DELAY1US 9 TIMES WITH COMPENSATION FOR THE 10TH
        RCALL DELAY1US
        RCALL DELAY1US
        RCALL DELAY1US
        RCALL DELAY1US
        RCALL DELAY1US
        RCALL DELAY1US
        RCALL DELAY1US
        RCALL DELAY1US
        RCALL DELAY1US
        NOP
        ;RCALL SUB16
        ;RCALL SUB20
        RET
DELAY15US: ;;COMPENSATED
        RCALL DELAY10US
        RCALL DELAY1US
        RCALL DELAY1US
        NOP
        NOP
        NOP
        NOP
        NOP
        NOP
        NOP
        NOP
        NOP
        ;RCALL SUB16
        ;RCALL SUB20
        RET
DELAY50US: ; CALLS DELAY10US 9 TIMES WITH COMPENSATION FOR THE 10TH
        RCALL DELAY10US
        RCALL DELAY10US
        RCALL DELAY10US
        RCALL DELAY10US
        RCALL DELAY1US
        RCALL DELAY1US
        RCALL DELAY1US
        RCALL DELAY1US
        RCALL DELAY1US
        RCALL DELAY1US
        RCALL DELAY1US
        RCALL DELAY1US
```

```
        RCALL DELAY1US
        NOP
        ;RCALL SUB16
        ;RCALL SUB20
        RET
DELAY100US: ; CALLS DELAY10US 9 TIMES WITH COMPENSATION FOR THE 10TH
        RCALL DELAY10US
        RCALL DELAY10US
        RCALL DELAY10US
        RCALL DELAY10US
        RCALL DELAY10US
        RCALL DELAY10US
        RCALL DELAY10US
        RCALL DELAY10US
        RCALL DELAY10US
        RCALL DELAY1US
        RCALL DELAY1US
        RCALL DELAY1US
        RCALL DELAY1US
        RCALL DELAY1US
        RCALL DELAY1US
        RCALL DELAY1US
        RCALL DELAY1US
        RCALL DELAY1US
        NOP
        ;RCALL SUB16
        ;RCALL SUB20
        RET
DELAY500US:
DELAY:  ; UPDATED TO 500US
        RCALL DELAY100US
        RCALL DELAY100US
        RCALL DELAY100US
        RCALL DELAY100US  ;400US
        RCALL DELAY10US
        RCALL DELAY10US
        RCALL DELAY10US
        RCALL DELAY10US
        RCALL DELAY10US
        RCALL DELAY10US
        RCALL DELAY10US
        RCALL DELAY10US
        RCALL DELAY10US  ;490US
        RCALL DELAY1US
        RCALL DELAY1US
        RCALL DELAY1US
        RCALL DELAY1US
        RCALL DELAY1US
        RCALL DELAY1US
        RCALL DELAY1US
        RCALL DELAY1US
        RCALL DELAY1US
        NOP
        ;RCALL SUB16
        ;RCALL SUB20
        RET
DELAYMX:
        RCALL DELAY
        RET
DELAY1MS:
DELAY1000US:
DELAYM3X:  ;UPDATED TO 1000US
        RCALL DELAY100US
        RCALL DELAY100US
        RCALL DELAY100US
        RCALL DELAY100US
        RCALL DELAY100US
        RCALL DELAY100US
        RCALL DELAY100US
        RCALL DELAY100US
        RCALL DELAY100US  ;900US
```

```
        RCALL DELAY10US
        RCALL DELAY10US
        RCALL DELAY10US
        RCALL DELAY10US
        RCALL DELAY10US
        RCALL DELAY10US
        RCALL DELAY10US
        RCALL DELAY10US
        RCALL DELAY10US  ;990US
        RCALL DELAY1US
        RCALL DELAY1US
        RCALL DELAY1US
        RCALL DELAY1US
        RCALL DELAY1US
        RCALL DELAY1US
        RCALL DELAY1US
        RCALL DELAY1US
        RCALL DELAY1US
        NOP
        ;RCALL SUB16
        ;RCALL SUB20
        RET
DELAYM:  ;APPROXIMATELY 2MS
        RCALL DELAY1MS
        RCALL DELAY1MS
        RET
DELAY10MS:
DELAYM2:  ; UPDATED TO 10MS
        RCALL DELAY1MS
        RCALL DELAY1MS
        RCALL DELAY1MS
        RCALL DELAY1MS
        RCALL DELAY1MS
        RCALL DELAY1MS
        RCALL DELAY1MS
        RCALL DELAY1MS
        RCALL DELAY1MS   ; 9MS
        RCALL DELAY100US
        RCALL DELAY100US
        RCALL DELAY100US
        RCALL DELAY100US
        RCALL DELAY100US
        RCALL DELAY100US
        RCALL DELAY100US
        RCALL DELAY100US
        RCALL DELAY100US  ;9.900MS
        RCALL DELAY10US
        RCALL DELAY10US
        RCALL DELAY10US
        RCALL DELAY10US
        RCALL DELAY10US
        RCALL DELAY10US
        RCALL DELAY10US
        RCALL DELAY10US
        RCALL DELAY10US  ;9.990MS
        RCALL DELAY1US
        RCALL DELAY1US
        RCALL DELAY1US
        RCALL DELAY1US
        RCALL DELAY1US
        RCALL DELAY1US
        RCALL DELAY1US
        RCALL DELAY1US
        RCALL DELAY1US
        NOP
        ;RCALL SUB16
        ;RCALL SUB20
        RET
DELAY100MS:
DELAYM3:   ; UPDATED TO 100MS
        RCALL DELAY10MS
        RCALL DELAY10MS
```

```
RCALL DELAY10MS
RCALL DELAY10MS
RCALL DELAY10MS
RCALL DELAY10MS
RCALL DELAY10MS
RCALL DELAY10MS
RCALL DELAY10MS  ;90MS
RCALL DELAY1MS
RCALL DELAY1MS
RCALL DELAY1MS
RCALL DELAY1MS
RCALL DELAY1MS
RCALL DELAY1MS
RCALL DELAY1MS
RCALL DELAY1MS
RCALL DELAY1MS   ; 99MS
RCALL DELAY100US
RCALL DELAY100US
RCALL DELAY100US
RCALL DELAY100US
RCALL DELAY100US
RCALL DELAY100US
RCALL DELAY100US
RCALL DELAY100US
RCALL DELAY100US  ;99.90MS
RCALL DELAY10US
RCALL DELAY10US
RCALL DELAY10US
RCALL DELAY10US
RCALL DELAY10US
RCALL DELAY10US
RCALL DELAY10US
RCALL DELAY10US
RCALL DELAY10US  ;99.990MS
RCALL DELAY1US
RCALL DELAY1US
RCALL DELAY1US
RCALL DELAY1US
RCALL DELAY1US
RCALL DELAY1US
RCALL DELAY1US
RCALL DELAY1US
RCALL DELAY1US
NOP
;RCALL SUB16
;RCALL SUB20
RET
DELAY500MS:
DELAYM4:    ; UPDATED TO 500MS
RCALL DELAY100MS
RCALL DELAY100MS
RCALL DELAY100MS
RCALL DELAY100MS  ;400MS
RCALL DELAY10MS
RCALL DELAY10MS
RCALL DELAY10MS
RCALL DELAY10MS
RCALL DELAY10MS
RCALL DELAY10MS
RCALL DELAY10MS
RCALL DELAY10MS
RCALL DELAY10MS  ;490MS
RCALL DELAY1MS
RCALL DELAY1MS
RCALL DELAY1MS
RCALL DELAY1MS
RCALL DELAY1MS
RCALL DELAY1MS
RCALL DELAY1MS
RCALL DELAY1MS
RCALL DELAY1MS   ; 499MS
RCALL DELAY100US
```

```
        RCALL DELAY100US
        RCALL DELAY100US
        RCALL DELAY100US
        RCALL DELAY100US
        RCALL DELAY100US
        RCALL DELAY100US
        RCALL DELAY100US
        RCALL DELAY100US  ;499.900MS
        RCALL DELAY10US
        RCALL DELAY10US
        RCALL DELAY10US
        RCALL DELAY10US
        RCALL DELAY10US
        RCALL DELAY10US
        RCALL DELAY10US
        RCALL DELAY10US
        RCALL DELAY10US  ;499.990MS
        RCALL DELAY1US
        RCALL DELAY1US
        RCALL DELAY1US
        RCALL DELAY1US
        RCALL DELAY1US
        RCALL DELAY1US
        RCALL DELAY1US
        RCALL DELAY1US
        RCALL DELAY1US
        NOP
        ;RCALL SUB16
        ;RCALL SUB20
        RET
SEC1:
DELAY1SEC:   ; 1.000 000 875 SEC
        RCALL DELAYM4
        RCALL DELAYM4
        RET
SEC5:  ; 5.000 000 875 SEC
DELAY5SEC:
        RCALL DELAYM4
        RCALL DELAYM4
        RCALL DELAYM4
        RCALL DELAYM4
        RCALL DELAYM4
        RCALL DELAYM4
        RCALL DELAYM4
        RCALL DELAYM4
        RCALL DELAYM4
        RCALL DELAYM4
        RET
SEC10: ; 10.000 000 875 SEC
DELAY10SEC:
        RCALL DELAYM4
        RCALL DELAYM4
        RCALL DELAYM4
        RCALL DELAYM4
        RCALL DELAYM4
        RCALL DELAYM4
        RCALL DELAYM4
        RCALL DELAYM4
        RCALL DELAYM4
        RCALL DELAYM4
        RCALL DELAYM4
        RCALL DELAYM4
        RCALL DELAYM4
        RCALL DELAYM4
        RCALL DELAYM4
        RCALL DELAYM4
        RCALL DELAYM4
        RCALL DELAYM4
        RCALL DELAYM4
        RCALL DELAYM4
        RET
SEC20:
```

```
DELAY20SEC: ; 20.000 000 875 SEC
        RCALL DELAYM4
        RCALL DELAYM4
        RCALL DELAYM4
        RCALL DELAYM4
        RCALL DELAYM4
        RCALL DELAYM4
        RCALL DELAYM4
        RCALL DELAYM4
        RCALL DELAYM4
        RCALL DELAYM4
        RCALL DELAYM4
        RCALL DELAYM4
        RCALL DELAYM4
        RCALL DELAYM4
        RCALL DELAYM4
        RCALL DELAYM4
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        RCALL DELAYM4
        RCALL DELAYM4
        RET
RSLOW3:
        MOV     R18,R16
        ANDI    R16,0XF0
        ANDI    R18,0X0F
        SWAP    R18
        CBR     R16,0X0C
;       ORI     R16,0X03
        OUT     PORTD,R16
        RCALL   DELAY50US
        SBR     R16,0X08
        OUT     PORTD,R16
        RCALL   DELAY50US
        CBR     R16,0X08
        OUT     PORTD,R16
        RCALL   DELAY50US
        CBR     R18,0X0C
;       ORI     R18,0X03
        OUT     PORTD,R18

        RCALL   DELAY50US
        SBR     R18,0X08
        OUT     PORTD,R18
        RCALL   DELAY50US
        CBR     R18,0X08
        OUT     PORTD,R18
        RCALL   DELAY50US
        RET
RSLOW2:
        CBR     R16,0X0C
;       ORI     R16,0X03
```

```
        OUT     PORTD,R16
        RCALL   DELAY50US
        SBR     R16,0X08
        OUT     PORTD,R16
        RCALL   DELAY50US
        CBR     R16,0X08
        OUT     PORTD,R16
        RCALL   DELAY50US
        RET
RSLOW:
        ORI     R16,0X80
        MOV     R18,R16
        ANDI    R16,0XF0
        ANDI    R18,0X0F
        SWAP    R18
        CBR     R16,0X0C
;       ORI     R16,0X03
        OUT     PORTD,R16
        RCALL   DELAY50US
        SBR     R16,0X08
        OUT     PORTD,R16
        RCALL   DELAY50US
        CBR     R16,0X08
        OUT     PORTD,R16
        RCALL   DELAY50US
        CBR     R18,0X0C
;       ORI     R18,0X03
        OUT     PORTD,R18
        RCALL   DELAY50US
        SBR     R18,0X08
        OUT     PORTD, R18
        RCALL   DELAY50US
        CBR     R18,0X08
        OUT     PORTD, R18
        RCALL   DELAY50US
        RET
RSHIGH:
        MOV     R18,R16
        ANDI    R16,0XF0
        ANDI    R18,0X0F
        SWAP    R18
        SBR     R16,0X04
        CBR     R16,0X08
;       ORI     R16,0X03
        OUT     PORTD,R16
        RCALL   DELAY50US
        SBR     R16,0X08
        OUT     PORTD,R16
        RCALL   DELAY50US
        CBR     R16,0X08
        OUT     PORTD,R16
        RCALL   DELAY50US
        SBR     R18,0X04
        CBR     R18,0X08
;       ORI     R18,0X03
        OUT     PORTD,R18
        RCALL   DELAY50US
        SBR     R18,0X08
        OUT     PORTD,R18
        RCALL   DELAY50US
        CBR     R18,0X08
        OUT     PORTD,R18
        RCALL   DELAY50US
        RET
INTLCD:
        RCALL   DELAY1SEC
        LDI     R16,0X20
        RCALL   RSLOW2
        RCALL   DELAYM
        LDI     R16,0X2C
        RCALL   RSLOW3
        RCALL   DELAYM
```

```
        LDI     R16,0X0C
        RCALL RSLOW3
        LDI     R16,0X01
        RCALL RSLOW3
        RCALL DELAYM
        LDI     R16,0X06
        RCALL RSLOW3
        RCALL DELAY50US
        RET
CLRSCR:
CLRSCREEN:
        LDI     R16,0X01
        RCALL RSLOW3
        RCALL DELAYM3
        RET
BINTODEC:
PRESULT1:
        RCALL RESULTB
        LDI     R17,0X0A
        ADD R17, R16
        STS     RESULT1, R17
        RET
RESULTB:
        CLR     R17
        STS     DRESULT1,R17
        STS     DRESULT2,R17
        LDS     R16,RESULT1
RESULTC:
        LDI     R17,0X64
        SUB     R16,R17
        BRCC    RESULTD
        RJMP    RESULTE
RESULTD:
        LDS     R17,DRESULT2
        INC     R17
        STS     DRESULT2,R17
        RJMP    RESULTC
RESULTF:
        LDI     R17,0X64
        ADD R16,R17
RESULTG:
        LDI     R17,0X0A
        SUB     R16,R17
        BRCC    RESCONT
        RET
RESCONT:
        LDS     R17,DRESULT1
        INC     R17
        STS     DRESULT1,R17
        RJMP    RESULTG
RESULTE:
        LDS     R17,RESULT2
        CPI     R17,0X00
        BREQ    RESULTF
        INC     R16
        LDI     R17,0XFF
        ADD     R16,R17
        LDS     R17,RESULT2
        DEC     R17
        STS     RESULT2,R17
        RJMP    RESULTD
```