Analysis and Implementation for a Walking Support System for Visually Impaired People

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4 authors:

Eklas Hossain
Boise State University

Md Raisuddin Khan
International Islamic University Malaysia

Riza Muhida
Universitas Bandar Lampung

Ahad Ali
Lawrence Technological University

TERRAIN DETECTION AND HARDWARE IMPLEMENTATION FOR WALKING SUPPORT SYSTEM

BY

SK EKLAS HOSSAIN

INTERNATIONAL ISLAMIC UNIVERSITY MALAYSIA

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SK EKLAS HOSSAIN

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Kulliyyah of Engineering
International Islamic University
Malaysia

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ABSTRACT

This research designs a new walking support system for the visually impaired people in order to help them navigate without any assistance from others or using any guide cane. With the help of this device a user can move independently and able to walk freely almost like a normal person. Researches on walking support system for Blind face challenges in detecting information about terrain, especially of stairs and holes in front of the user. In detecting terrain, researchers have tried different sensors like ultrasonic, laser, camera etcetera, and different algorithm; however, satisfactory outcome has not yet been achieved and white cane is still the most used walking support for the blind people. This is because almost all the research outcomes failed to address the crucial requirements of the walking support systems, like low energy requirement, light weight, hole and stair detection capabilities. In the design of our new device all of these issues have been taken care and implemented successfully. In this research a belt, wearable around the waist is equipped with four ultrasonic sensors and one sharp infrared sensor. A mathematical model has been developed based on the specifications of the ultrasonic sensors to identify optimum orientation of the sensors for detecting stairs and holes. These sensors are connected to a microcontroller along with a laptop so that we can get sufficient data for analyzing terrain on the walkway of the blind. Based on the analyses of the acquired data we have developed an algorithm capable of classifying various types of obstacles. Later we removed the computer and used the microcontroller only for our system, which is the device, named ‘Belt for Blind’ to help them navigate through detection of their environment. The device is also equipped with a servo motor and a buzzer to generate outputs that inform the user about the type of the obstacle ahead. Besides, we have tried image processing to analyze images of obstacles like stair up, and stair down, but it did not show worth result. The achievements that we have made in this project are selection of proper hardware, development of mathematical model, design and fabrication of prototype, development of algorithm for detecting obstacles and development of GUI for data acquisition. On top of these achievements the device is light, cheap and consumes less energy. However, this device is limited to standard pace of mobility of the user and cannot differentiate between animate and inanimate obstacles. Thus further research is recommended to overcome these deficiencies to improve mobility of blind people.

ملخص البحث

هذا المشروع تصميمات جديدة للمشي للعميان من أجل مساعدتهم دون أية مساعدة من غيرهم أو باستخدام أي دليل بالعصا. وبمساعدة لهذه الوسيلة أن المستعمل قادر على المشي بحرية التحرك بشكل مستقل مثل الشخص العادي. والبحوث عن المشي دعمت نظاماً لمواجهة التحديات التي تواجه المكفوفين في كشف معلومات حول الجدر خاصة بالنسب الدرج والجحر. والباحثون بذلوا كل الجهود لاختراع أجهزة متنوعة وجديدة للتنبيه على العوائق التي تواجه هؤلاء الأشخاص أمامهم خلال المشي. ولكنهم في هذا المجال لم ينجحوا بقدر الاكتفاء لتصميم الجهاز المناسب. لأنهم لم يتبعوا طرقاً مناسبة و وسائل متيحة للنجاح. و في هذا البحث اخترعنا حزاماً يوضع حول عراة الصدور مزود بأربعة ماكينة تعمل بالموجات فوق الصوتية بشكل حاد من الأشعة تحت الحمراء بأجهزة الاستشعار. المنجزات التي حققناها في هذا المشروع من المعدات واختيار المناسب ووضع نموذج رياضي أو في تصميمها أو تلفيق نموذجي. ووضعنا العراقيل خوارزمية للاكتشاف وللحصول على البيانات والتطوير للغاية. ويأتي هذا الجهاز هو الانجازات خفيفة زهيدة الثمن و يستهلك أقل من الطاقة. لكن هذه الوسيلة تقتصر على إيقاع حركية موحدة المستعملة لتنشيط أو جامدة لا تميز بين العقبات. وهذا الجهاز هو فقط ميكرو كونترولار. ثم أننا استعملنا الكمبيوتر لاستخدام نظامنا. وهو الجهاز الذي يحمل اسم "الحزام" للمكفوفين تساعدهم على بينتها و لمطالعة كشفها. كما أن هذا الجهاز مزود تعرف "بوزار" بمحرك من أجهزة لتحقق نتائج المستخدمين حول نوع العائق المنتظرة. أضيف إلى ذلك أننا حاولنا لقيام تحليل الصور صور الستاير عقبات حتى أسفل الستاير لكنها لم تظهر نتيجة قيمة.

DECLARATION

I hereby declare that this dissertation is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

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To my beloved parents

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TABLE OF CONTENTS

CHAPTER 4: TERRAIN DETECTION EXPERIMENT AND DATA ANALYSES

CHAPTER 5: ALGORITHM AND HARDWARE DEVELOPMENT

CHAPTER 6: CONCLUSION AND RECOMMENDATION

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

The concept of walking aids for blind people is not new. A great deal of research has been performed to improve autonomy of visually impaired people and especially their ability to explore the environment. During the last two decades a lot of research has been done on electronics travel aids, and prior to this we have experienced some researches with non electronics devices to help the visually-impaired people. Orientation, Navigation and Mobility are perhaps three of the most important aspects of human life. Significant features of information to aid navigation for active mobility are passed to human through the most complex sensory system, the vision system. This visual information forms the basis for navigational tasks; as such an individual with impaired vision is at a disadvantage because appropriate information about the environment is not available. The term blindness refers to people who have no sight at all as well as to those considered as blind have limited vision, which cannot be said to be severely visually impaired, (WHO, 1998). The major causes of blindness are age-related macular degeneration, cataracts, glaucoma, diabetic retinopathy, trachoma, onchocerciasis, by birth, lack of eye care and accident (Times of India, 2000).

Mobility is an ability of movement within the local environment. It is also the ability to move with the knowledge of objects and obstacles in front. Blind individuals find their mobility difficult and hazardous, because they cannot easily identify the obstacles for comfortable navigation. The autonomous navigation without collision and with discrimination of objects becomes the major task for them to face their daily life requirement.

Since early 1950’s several efforts in providing travel aids for visually impaired people has been on development. They ranged from the simple cane to advanced electronic aids (Lofving, 1998). The development of other assisting devices to aid visually impaired people in their everyday life has been increasing. In some cases, solutions to providing sensory supplementation such as Braille through electronic reading machines have been very effective. However, truly adequate solutions for navigation assistance for visually impaired have not yet been achieved. A number of devices have already been developed to address some of the difficulties faced by visually impaired people with regard to travel (Baldwin, 1998). This study therefore aims at examining the viability of different types of devices for mobility aid of blind; either using sensors or cameras, but some of them used both.

1.2 BLINDNESS AND BLIND POPULATION- AN OVERVIEW

Blindness is the condition of lacking visual perception due to physiological or neurological factors. Various scales have been developed to describe the extent of vision loss and define blindness. Total blindness is the complete lack of form (ICO, 2002) and visual light perception, and is clinically recorded as NLP, an abbreviation for "no light perception." Blindness is frequently used to describe severe visual impairment with residual vision. Those described as having only light perception have no more sight than the ability to tell light from dark and the general direction of a light source.

Visual impairment is one of the most common disabilities worldwide. WHO reported that due to the lack of epidemiological data, especially form the developing and under developed countries, the exact number of blind persons in the world is not known. In 1994, WHO estimated that it was around 38 million with a further 110 million cases of low vision, which are at risk of becoming blind? In 1998, the total population of visual impairment was more than 150 million people (WHO, 1998). Currently, there is a total of about 45 million blind people in the world and a further 135 million have low vision and this number is expected to double by 2020 (Times of India, 2000). The number of people who become blind each year is estimated to be 7 million. Over 70% of the people with vision problem receive treatment and their vision is restored. Thus the number of blind persons worldwide is estimated to increase by up to 2 million per year (WHO, 1997). Eight percent of these cases are ageing-related. In most countries of Asia and Africa, it accounts for over 4o% of all blindness. It is also estimated that, currently, there are approximately 15 million blind people in South East Asia Region or one-third of the blind population of the world. China accounts for about 18% of the worlds blind and is estimated to have the largest number of blind people in the world. There are a quarter of a million people in the UK who are registered as visually impaired. However, the UK actually has nearly one million people entitled to register as a visually impaired person, and 1.7 million with the vision difficult. This represents over three percent of the UK population (NFB, 2002). In Britain, more than twenty thousand children grow up with visual impairment, and there are two hundred vision-related accidents per day in the UK alone (Leonard and Gordon, 1999; Viisola, 1995). There are approximately 10 million visually impaired people in the United States (AFB, 2001). In addition, statistics state that for every seven minutes, someone in America is becoming visually impaired (Blasch, 1999). In Malaysia, alarming increment in blind population is noted with about 46.9% from 1990 to 1999. By September 2000, there were about 13,835 registered in Blind Associations and it is predicted that, it might be less than 50% of the total blind population in the country (JKM, 2000; ERM, 2001).

The largest number of visually impaired people falls into the sensor citizen category; in fact sixty-six percent of people with impaired vision are over seventy-five year old (Papenmeier, 1997; Lacey and Dawson-Howe, WHO, 1997a).

1.3 PROBLEM STATEMENT

There are many blind people in Malaysia. Usually, to work outdoor, they face difficulties. This is why many of them use a guide cane that is considered as cheap and helpful to them. This purely mechanical device is usually used to detect the surface of the ground, obstacle in front, holes, staircase and many more. A guide cane is so economical and light that it can be folded and can be brought to any places without any difficulty. However, a guide cane also has its drawback. It must be used many times in order for the user to detect any change to the ground or to avoid obstacle. Therefore, only trained users will be able to use the guide cane defiantly.

Besides that, blind person needs to scan the walking area continuously while walking. Another drawback is that the guide cane cannot detect any obstacle within the range of 2 to 3 meters. A guide cane can only detect an object when it has a contact with it. If there is no contact, the user will eventually bump to it. Another example is that the guide cane is not a device that can detect objects from above the waist such as obstacles close to the head. And lastly, it cannot detect any moving object and therefore are exposed to dangers of hitting vehicles or even moving animals.

Another option for a blind person is to use a guide dog or horse. However, a both dog and horse will cost a lot as it needs an extensive training to help the blind person. In Islam, all Muslims are prohibited to have any kind of contact with dogs. Therefore, it is not applicable for a blind Muslim. Usually, blind people are not self dependent and this will be difficult for them to take care of the dog besides themselves.

The performance of the above steps can be achieved for a blind person using the correct technology. Some of the technological achievements in this line are already available in the market like Laser Cane, Mowat Sensor, Talking Sings, Sonar System and so on. However, each of them possesses some drawback.

In an unfamiliar environment, either a mobile robot or a blind person has a common point. That is they cannot detect an object without any help from a device. Both of them have the ability to walk or move to a certain point but a mobile robot uses sensors in order to avoid any obstacle. If this technology is sued on the blind person, it can be a big help for them to walk safely and reduce the danger when walking without a guide cane.

When multiple sensors are installed on the blind person, then they do not need to scan their area to walk in front. The transfer of mobile robot technology is actually a new development in order to help this type of community. In the past, robots have been used to aid the blind person to walk. But this new technology assists the user to walk without having any difficulty. Besides that, it is more economical to apply the technology directly to the person rather than buying a complicated robot that will cost a lot. In this case, it becomes difficult to mimic nature in its entirety of human vision system. A blind user will utilize a guide cane to scan obstacles in front of him/her, waving the guide cane from left from right and vice versa continuously. This scanning is not effective because there is a possibility for the guide cane to miss a spot as the user is waving the guide cane, it may lead to a collision. Besides, the blind user may reach his destine by taking help from healthy vision person. However, the blind needs to adjust his time according to the availability of his companion who will guide him. So this will restrict his freedom to go other places according to his will. To overcome this problem, we are going to use an array of sensor with different orientation so that we can easily map the environment. Having with modern technology, the walking support systems for blind are still not sophisticated in terms of mobility, safety and cost; this problems lead to motivation of designing a prototype of smart walking support system for visually impaired people. The walking support system will help the blind user to avoid obstacles in the way of his destination.

1.4 RESEARCH OBJECTIVES

The objectives of this study are:

1. To develop a sensing system for terrain detection around a blind person.
2. To develop algorithm for interpreting types of obstructions around a blind user from the mapped data.
3. To develop actuation system that interprets the terrain around the user.
4. To validate performance of terrain detection hardware and software.

1.5 RESEARCH METHODOLOGY

To achieve the objective of this research, the following steps are taken:

1. The study will begin with exploring walking support system and analyzing its problems through extensive literature survey.
2. Detection of Terrain data using Ultrasonic Sensor and Sharp IR sensor.
3. Analysis of the sensed data using computer for detecting proper terrain.
4. Development of an algorithm for interpreting terrain.
5. Integration of sensors and actuators using mikroC Programming for a Micro-Controller.
6. Design and development of a prototype for blind support system.
7. Performance evaluation of the anticipated novel ETA device.

1.6 SCOPE OF WORK

1. Extended literature review

2. Select proper component for experiment

3. Malaysian Association for Blind (MAB) interview

4. Development of a Mathematical Model

5. Design Experimental Setup and instrumentation

6. Design of a GUI for data logging to computer

7. Develop proper algorithm for sensing data from environment

8. Design actuation system for blind user.

9. Verify results using blind user.

1.7 THESIS ORGANIZATION

The thesis is divided into six chapters. The brief descriptions of each chapter are given below:

1. Chapter 1: An introduction to the development of walking support system is given in this chapter. The background, blindness and blind population-an overview, problem statement, objective, research methodology and the thesis outline is discussed.
2. Chapter 2: This chapter delves in the past and current literature pertaining to the topic of walking support system. Previous works on the issue are presented and evaluated.

3. Chapter 3: This chapter briefly revisits the problem statement regarding the limitations of the traditional ETA device, and based on this information designs a system to overcome all those problems.
4. Chapter 4: Here the experimental setup is shown along with its mathematical model.
5. Chapter 5: A detailed description of the prototype is given here. The guide lines for developing terrain detection algorithm are discussed in detail. The performance of the prototype is monitored and other results are given.
6. Chapter 6: A summary of the research outcome is presented in conclusion, including the measure of success of the undertaking. Limitations of the work are mentioned and suggestions for future works offered.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Electric Assistive Technologies (EATs) provide the blind people spatial information about the environment in assisting them for navigation. Early technology uses ultrasonic to detect the obstacles in their path and distance of the obstacle is provided as vibration or as sound signal to the blind. Later, due to the developments in high speed computer and sensors, the efforts are directed to develop sophisticated and more intelligent ETAs.

2.2 BLIND NAVIGATION AIDS

The progress of the ETA development can be divided into two stages (Wong, 2000; Sainarayanan, 2002).

i. Early ETAs

ii. Modern ETAs

2.2.1 Early ETAs

Guide dogs **(**Iona and Peter Opie, 1952**)** are assistance dogs trained to lead blind or vision impaired people around obstacles. Although the dogs can be trained to navigate various obstacles, they are partially (red-green) color blind and are not capable of interpreting street signs. The human half of the guide dog team does the directing, based upon skills acquired through previous mobility training. The handler might be likened to an aircraft's navigator, who must know how to get from one place to another, and the dog is the pilot, who gets them there safely.

In several countries, guide dogs, shown in Figure 2.1, along with most service and hearing dogs, are exempt from regulations against the presence of animals in places such as restaurants and public transportation.

Figure 2.1 a blind man is led by his guide dog in Brasília, Brazil.

Furthermore, a guide horse (*Panda and Edie, 1999*) is an experimental mobility option for blind people who do not wish to or cannot use a guide dog. They are provided by The Guide Horse Foundation, founded in 1999 to provide miniature horses as assistance animals to blind users living in rural environments. There are several perceived advantages of using a horse rather than a dog. Miniature horses (Figure 2.2), with an average lifespan of thirty years, live much longer than dogs, and for those allergic to or frightened of dogs, a horse could make a good alternative. However, while a dog can adapt too many different home situations, a horse will still require a barn and pasture when not on duty. Also, though they can be trained to relieve themselves on command, the period of time a horse can actually wait is significantly shorter than a dog's. Guide horse users may also find difficulty in transporting a miniature horse on limited-spaced public transportation, such as on buses or taxis.

Figure 2.2 a man with a guide horse in an airport in US

Besides, a white cane (James Biggs, 1921) is often associated with visually impaired people for their movement. Some form of stick is shown in Figure 2.3, for probing when traveling has been used informally for centuries. Real and more complex developments occurred after the Second World War and through the years 1950s and 1960s. Advances in electronics and circuit miniaturization also aided the development of these devices into portable mobility machines. It can be concluded by surveying the literature that the period of early ETAs is between 1950s-1970s (Baldwin, 1998; sonic Vision, 1999).

Figure 2.3 A white cane, the international symbol of blindness

Most of the early ETAs used ultrasonic and sonar sensors for obstacle detection. The technology used is relatively inexpensive; ultrasound emitters and detectors are quite small and they can easily be mounted without the need for more complex and costly additional circuitry. Ultrasound systems are available in many forms and in many shapes and sizes. The late John Dupress, a totally blind psychologist, showed in 1962 that he was perceptive of the needs of a blind person, and it is very significant that most of what he said remains true, 20 years later. ‘In the first place it cannot be assumed that a blind person ought to want to travel some place because of some device or rehabilitation program! If a blind person is to undergo constant stress and danger travelling in unfamiliar and familiar environments, he must have a good reason to do so. You will find therefore that only when more blind people secure jobs, fulfill their interests and are integrated into society will they have a readiness for travel’. The devices emit ultrasonic signals, upon reflections from the obstacles, the distance of the obstacle is manipulated and it is provided in terms of vibration or sound. However, the way in which they aid is limited mainly due to inherent property of multiple reflections. There had been several devices during this period (Dupress, 1963; Duen, 1998; Heyes, 1984, Kaczmarek, 1991). Laser cane (Figure 2.4) could be operated with one hand, freeing the other hand for other normal tasks (i.e. carrying a suitcase, brief case or shopping bags, etc.), and able to indicate if an obstacle is hand height, waist height, or low for drop-off. As a primary mobility device, the Laser cane requires no other devices to be used in conjunction with it. The Laser cane is made in the same shape of the universally familiar guide cane, with built in sensing electronics, making it a primary device.

Figure 2.4 Laser cane fitted with three laser transmitters and focused receivers to detect obstacles in a blind person's travel path

Russsel Path sounder (Duen, 1998) was invented in 1965 and it is one of the most early ETAs. Chest mounted board with two ultrasonic sensors produce three levels of click sound to indicate the distance.

The MOWAT (Mowat, 1970) sensor is a hand-held torch like device that radiates ultrasonic signals and receives the reflected signal from the obstacle. It gives a few level of tactile vibration depending on distance. Frequency of vibration increases as the distance of the obstacle decreases. It has a scanning range from 1 meter to 4 meter.

The Sonic guide (Goldstein, 1981) or Binaural Sensory Aid was advancement of the Sonic Torch, is shown in Figure 2.5. It has wide beam ultrasonic transmitter mounted in the centre of the spectacle and a receiver on each side of the transmitter. Depending on the distance of the obstacle the sound tones are fed back to the right and left ear of the blind. Children’s version of the Sonic guide has sensors mounted in a helmet (Baldwin, 1998; Shoval, 1998).

Figure 2.5 Kay's Sonic Torch

Nottingham obstacle detector (AG Dodds, 1981) works in an analog technique as that of MOWAT sensor, but produces an audible note when the obstacle is within the device range, the maximum range being around two meters. Through Nottingham obstacle detector can be easily used with the long cane, it is still needed to be held in hand as the Sonic Torch. It produces 8 different sounds for 8 levels of distances (Heyes, 1984).

C-5 Laser Cane (Figure 2.6) was introduced in 1973. It has three transmitters and three photodiodes as receives. It produces two different tones and vibrations upon detection of obstruction within 4 meter range (Lofving, 1998; Benjamin, 1973).

Figure 2.6 binaural sensory aids for the blind (Sonic guide) using wide band-width CWFM echo-location principles and a binaural display of distance and direction of multiple objects for sensing the environment up to 5m with a field of view of approximately 50 degree

Polaran gives two forms of outputs namely sound and vibration. The frequency of sound and vibration increases, as the blind gets closer to the objects. It has a selectable detection of ranges of 1 meter, 2.5 meter and 5 meter. Sensory 6 is also a head mounted spectacles with ultrasonic sensors. It creates sound tones with pitch inversely related to distance of the sensed obstacle. It has two modes of range; 2 meter and 3 meters (Baldwin, 1998).

By the 1970s, approximately 1000 mobility devices of these types had made their way into the market or were in development for the use by visually impaired people. In spite of the fact that these small ultrasonic devices provide an adequate amount of information regarding the distance of the obstacle, their responses are restricted as they only employ a relatively small number of ultrasonic emitters and receivers.

Some researchers attempted to solve this problem, in the late 1960s and the early 1970s, by building an array of tactile feedback devices and attaching them through standard camera. The captured image is processed and the significant information about the captured image was provided as stimulus by the vibrating device. Difficulties still existed with this new development since the information produced by the vibration is too complex to understand and therefore very difficult to use (Snaith, 1998).

There are some notable difficulties in the early ETAs such as

i. Some of the ETAs transfer the feedback signal to the blind in terms of vibrations, which is complex to understand.

ii. Most of the ETAs focus on the distance of the obstacles, while information on the size and other properties of obstacles are not provided.

iii. The user has to scan constantly and continuously to locate the obstacle in the path (expect for Sonic Guide and Path sounder), which is time consuming and it is similar to having a long cane.

iv. Improper calibration of the transducers may lead to serious effects.

2.2.2 Modern ETAs

By the early 1990s the focus has switched from mobility and obstacle detection to orientation and location. With the advanced development of the high sensitive sensors and computing devices, the research had been focused to new directions. Even though the complete performance satisfaction is not achieved, the inventers were able to tackle the limitation of the early ETAs. We can classify Modern ETAs based on sensing device like Sensor, Camera etc, and are narrated below respectively.

G 5 obstacle Detector uses optical cane technology. Light is emitted from an incandescent light. Obstacles can be detected by sensing the changes in the reflected light, and a tactile output is produced. Whenever the obstacle detector comes into the range of an obstacle, it would cause the handle to vibrate. The device is quite large and cannot be used successfully without a long cane (Heyes, 1984).

The main goal of this project, which started in the early 1990s in Japan, was to design a new mobility aid modeled after the bat's echolocation system (T. Ifukube 1991). 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.

The potential usefulness of a navigation aid is unquestionable to help the perception of the environment for visually impaired people. Bats are well-known examples, which can perfectly navigate by the help of ultrasonic echolocation without vision, and this technique is successfully applied in mobile robots. Independently from this field, real-time 3D sound generation has been developed to an accessible technology even in home PCs. Their basic idea is to connect these two threads using fast and power efficient DSP (Digital Signal Processor) to produce a small, portable instrument, which can be a useful navigation aid for the blind.

Figure 2.7 SuperBat on a user.

The ultimate goal is to indicate the environment obstacles by such a stereo sound effect as if it had oriented from the obstacle itself. The digital signal processor based system is able to determine the distance and the horizontal position of the obstacles in front of the user and to indicate the location of the nearest one by stereo sound through earphones. The DSP is equipped with suitable interface circuit connected to one ultrasound transmitter and two receivers, which can be mounted (Figure 2.7), e.g., on the hat of the blind person. Main functions of the device:

- Detecting nearest obstacles in front of the user by means of ultrasonic echolocation and indicating the distance and horizontal (2D) Position by spatial stereo sound effects.
- Information gathering from the environment via a radio subsystem. The radio subsystem consists of transceiver devices mounted on vehicles and public building and the mobile transceiver carried by the blind or visually impaired person who is used to identify the equipped building and vehicles. The system is particularly useful for providing information in navigation at traffic nodes. A built in voice synthesizer informs the user of the relevant data.

The components of the system are integrated in one, small size unit. The system, however, cannot solve the blinds' ultimate problem of the perfect environment perception. It has limits due to the characteristics of the ultrasound reflections. The deployment and widespread use of the information services built upon the radio component also requires further efforts (Sasaki, 1991).

Navbelt is developed by Borenstein and coworkers in University of Michigan [Shoval, 1992] as a guidance system, using a mobile robot obstacle avoidance system. The prototype as implemented in 1992 and it consisted of ultrasonic range sensors, a computer and earphones. The computer receives information from the eight ultrasonic sensors (Figure 2.8) 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.

Figure 2.8 NavBelt on a user

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 (no 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.

Robotic guide is a robot that guides a visually impaired person to help them navigate dynamic and complex indoor environment such as supermarket, office, and many more. Robotic Guide can solve problems which eventually can help the blind person in moving across an indoor environment easily. The solutions are as follows:

1. The robot can interact with other people in the environment, (e.g., ask them to yield or receive instructions.)
2. Robot-assisted navigation offers feasible solutions to two difficult permanent problems to wearable assisted navigation devices for people who are visually impaired: hardware miniaturization and portable power supply. The amount of body gear carried by the user is significantly minimized, because most of it can be mounted on the robot and powered from on-board batteries. Therefore, the navigation-related physical load is reduced.
3. The user can use robotic guides in conjunction with her conventional aids, (e.g., white canes and guide dogs).
4. Robotic guides can carry useful payloads, (e.g., suitcases and grocery bags).

Figure 2.9 Robotic Guide

The Robotic Guide (Figure 2.9) was first tested as a prototype in the USU CS Department. The CS Department occupies an area of 21,600 square feet in the multi-floor Old Main building on the south campus. The Department has 23 offices, seven laboratories, a conference room, a student lounge, a tutor room, two elevators, several bathrooms, and two staircases. Robotic Guide was built on top of the Pioneer 2DX robotic platform from the Active Media Corporation.

Robotic Guide’s navigation system includes a set of ultrasonic sensors used for local obstacle avoidance and radio frequency identification (RFID) reader and antenna that resided in a polyvinyl chloride (PVC) pipe structure mounted on top of the platform. The system included a laptop computer connected to the platform’s microcontroller. The RFID reader and antenna were used to detect small RFID tags placed in the environment. These tags can be attached to objects in the environment or worn on clothing. They do not require any external power source or direct line of sight to be detected by the RFID reader. The tags are activated by the spherical electromagnetic field generated by the RFID antenna with a radius of approximately 1.5 meters. Each tag is programmatically assigned a unique ID. When detected, RFID tags enable and disable local navigation behaviors.

The original interface was based on automatic speech recognition. The user would wear a wireless microphone with one ear headphone. The user would speck a destination and the robot would take him or her to that destination. However, speech was later abandoned after unsuccessful trails with users with visual impairments (Kulyukin, 1994).

Another patented device, the Taking Cane, has the ability to give speech output. It is also named as LOAVI (Laser Orientation Aid for Visually Impaired). The device is incorporated in a white cane, which has integrated laser transmitter and receiver. It works like optical radar. The environment around reflects the light emitted by the transmitter and the receiver receives it. The receiver is able to read the standard bar code indications, even at 10 to 15 meters away. As the light hits the sign, the device produces beep sound. On hearing the beep, the blind can press the button provided to listen to the pre-recorded speech, to indicate the user about doorways, traffic lights, exit signs etc. even the laser light emitted by the device is mentioned as harmless for normal condition, but it is unsafe when it is pointed to the eye of a sighted human (Lofving, 1998; Duen, 1998).

Hand held Nottingham obstacle detector was redesigned in 1984 and it was named Sonic pathfinder (Heyes, 1984; heyes, 1999). The sensors and transmitters were mounted to a header instead of previous hand held devices, with the identical sensor is denoted by the music tones. It has 3 ultrasonic transmitters and 2 receivers. The main drawback of this system is the inaccuracies caused by the ultrasonic sensor due to secular reflections and cross talks. This is the general problem faced by all sonar devices.

MIMS infrared mobility aid uses emitters and receives built into spectacle frames to provide obstacle detection. The optical transmitter emits a train of 20 millisecond pulses at a rate of 120Hz. One side of the spectacle frame contains the emitter and the other side contains the receiver. When an object is detected by the signals from the emitters, reflected signal is converted to an audible tone and it is heard through the user's earpiece. This is a secondary travel aid and should be used with a long cane or a guide dog (Smith-Kettlewell ins., 1999).

NavChair is a navigation system that is developed to provide mobility to individuals that find difficult to use a powered wheelchair due to cognitive, perceptual or motor impairments. The user will basically control the path of navigation and the wheelchair's motion along that path, and the NavChair restricts itself to ensure collision free travel. The prototype of NavChair is shown in Figure 2.10.

Figure 2.10 Prototype of NavChair assistive wheelchair navigation system

The NavChair currently offers several modes of operations to the user that is the general obstacle avoidance, door passage assistance, and close approach to an object.

This operating level works well with continuous input methods such as a joystick but is less suited to discrete methods such as voice control. A level requiring additional control from the NavChair system is appropriate when using voice to operate the NavChair (Figure 2.10) and the System must make some of the planning decisions (Levine, 2000).

Guide Cane is the second project by Borenstein (Borenstein, 2001) 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 (Figure 2.11).

The sketch of the prototype is shown in (left). 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 Guide cane, 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 Guide cane 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.

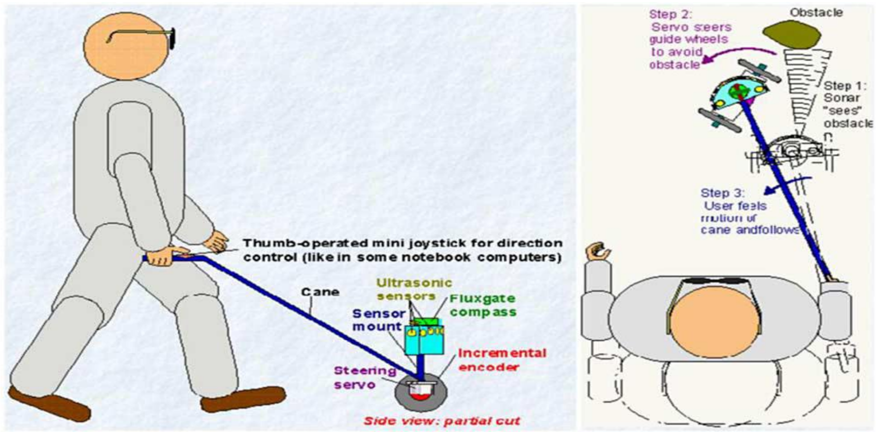


Figure 2.11 Schematic (left) and operation (right) of the Guide Cane prototype.

Smart shoe can detect an object a meter away by using an infrared sensor located on the shoe. A vibration will be given as an output with respect to the signal received once an object or obstacle is detected. The closer the user gets to the object, the faster the vibration of the motor. The motor which is attached at the shoe can vibrate at certain places on the shoe. This makes it easier for the user to change its direction if there is an obstacle in the way. Figure 2.12 shows a prototype of a smart shoe (Richard, 2003).

Figure 2.12 Smart Shoes for Blind

The shoe is being upgraded so that it is waterproof. This is done by embedding the circuitry system in the sole. Beside that, a system on detecting whether the user needs to go down a staircase is being developed for future implementation.

This project from researchers in Florida International University (FIU) is an obstacle detection system that uses 3-D specialized sounds based on readings from a multidirectional sonar system. The prototype (Figure 2.13) consists of two subsystems: the sonar and compass control unit, which consists of six ultrasonic range sensors pointing in the six radial directions around the user and a microcontroller; and the 3-D sound rendering engine consisting of headphones and a personal digital assistant (PDA) equipped with software capable of processing information from the sonar and compass control (Aguerrevere, 2004).

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. As seen in “Figure 2.13”, the design of the ranging unit is not ergonomic, but the system is small and wearable.

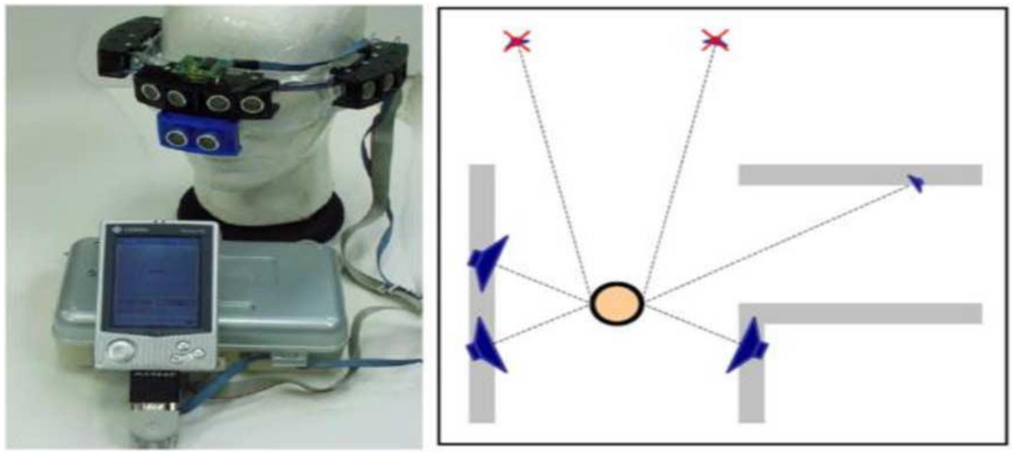


Figure 2.13 FIU project prototype (left) and an example of its operation (right).

CyARM is developed by researchers in Japan (Future University-Hakodate, Kanazawa University, Ochanomizu University and Fuji Xerox Company Ltd.). 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 (Ito, 2005).

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 (Figure 2.14).

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.

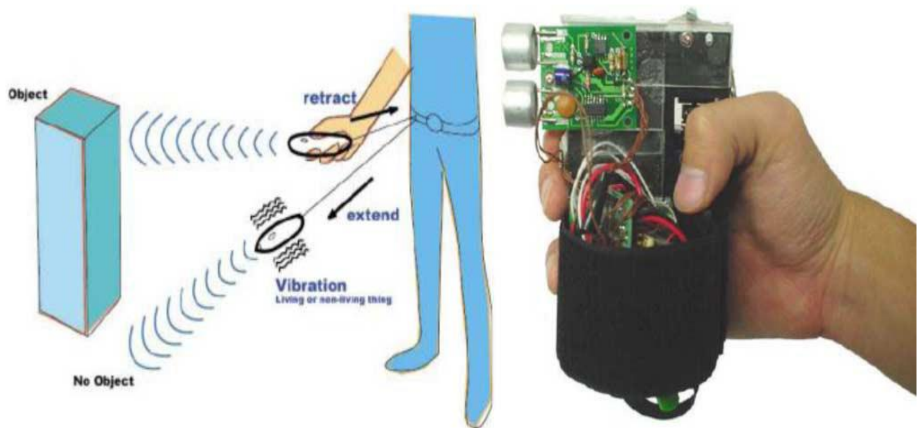


Figure 2.14 Prototype CyARM and the concept of operation.

Bouzit and coworkers from State University of New Jersey developed the tactile handle a device that will help visually impaired people navigate in familiar and unfamiliar environments without any assistance. The prototype is a compact (5 cm×5 cm×20 cm), lightweight, ergonomic, low-power (80 hours autonomy) handheld device. It embeds a microcontroller, a 4 × 4 tactile array, where each actuator matches one finger phalanx, and 4 sonar sensors, which detect obstacles in the front, left, right, and bottom.

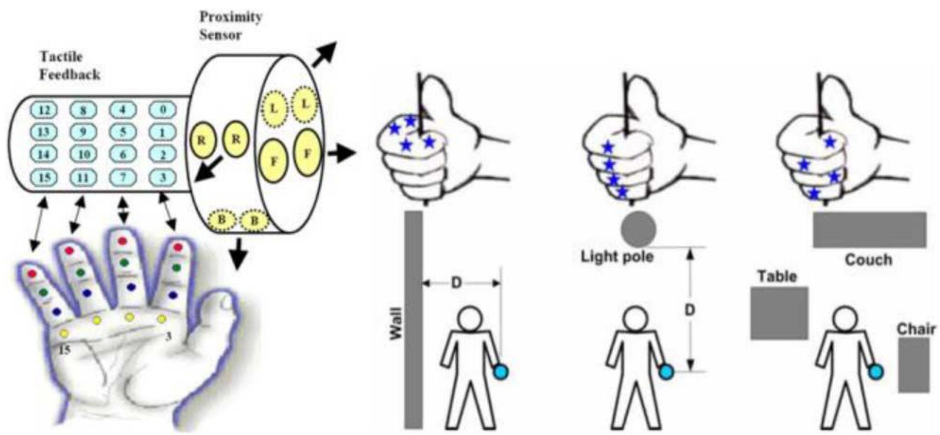


Figure 2.15 Description of vibrotactile actuators positions on the Tactile Handle and three navigation scenarios.

Information about the obstacles is given in an encoded form through the actuators. The location of the feedback represents different direction of the obstacle (Figure 2.15). 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 (Bouzit, 2004; Shah, 2006).

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.

Cardin from Ecole Polytechnique F´ed´erale de Lausanne (EPFL) developed a wearable system that detects obstacles of 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) (Cardin, 2007).

The microcontroller (Figure 2.16) gathers information from the sonars (Figure 2.17) 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 about the detection. The sonars and the vibrators are mounted on the clothes of the user, starting from one shoulder and ending at 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).

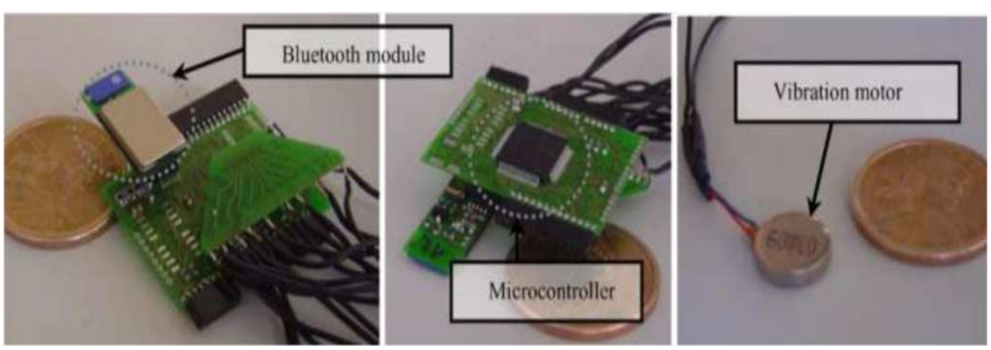


Figure 2.16 Hardware details of the EPFL prototype.

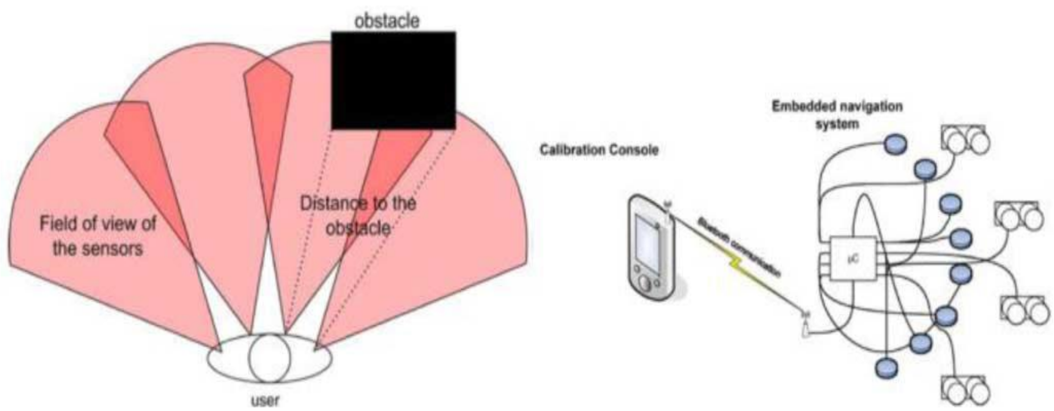


Figure 2.17 Operation and high-level design of the EPFL prototype.

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, consumes low power, and costs less. The cons are that it 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.

The smart cane is developed by the IIT Computer Science Development. It is basically a walking stick that helps the blind users to commute with city buses, walking around the outdoor and also indoor. It is also equipped with avoidance system.

The smart cane (Figure 2.18) has the ability to navigate the knee level and also gauge any obstacle 3 meters ahead. With a user-triggered wireless identification system, vibration warning signal manager and a battery-driven speaker, the stick can send radio frequency to a passing public bus with a small electronic box at its entrance, to detect the route number and speak it out. The user wearing a mono-earplug will hear the number of a bus and get proper directions to reach its entrance and exit (IIT, Delhi, 2007).

Figure 2.18 Smart Cane on a user

However, some of the researchers have used camera as a sensing device are discussed below.

Meijer started a project 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 shown in "Figure 19" 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 providing very promising feedback, but they required extensive training because of the complicated sound patterns (Meijer, 1992).

Figure 2.19 Implementation of the vOIce—"Seeing with sound" system (glasses with attached camera, ear speakers, and portable computer).

Adjouadi from Florida International University 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 consists 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 are good-lightning conditions (Adjouadi, 1992).

Sonic Eye (Reid, 1998) works with the concept of mapping of image to sound. It works by scanning the device's thin window over the object of interest from left to right. Features of the object in the top of the window are transferred to high pitch sound, while features in bottom are mapped to low pitch tones. It is used for two purposes, navigation and reading. While used for navigation, Sonic Eye can be hand to sweep the environment like torchlight or it can be head mounted. In reading mode, it is possible to read all alphabets with the mapped sound after adequate training; it is cited that by continuous practice the user can understand the continuous text. But users have to listen to each letters sound carefully to know the word, which requires a lot of patience and concentration. General problem of secular reflections in sonar also affects its accuracy.

Besides the technique presented above, there are multiple approaches for the vision assistance by non-wound methods. In the auditory interfaces realm, much process has been made since the new century. For presenting graphical scenes using non-speech sounds, we can utilize the physical tablet, the virtual-sonic grid, or the sound localization system. For instance, Yoshihiro and his workgroup proposed a support system for visually impaired people using three-dimension virtual sound. Its user is informed of the locations and movements of objects around him by the 3-D virtual acoustic display, which relies on HRTFs (Head Related Transfer Functions). Kamel and Roth developed a GUESS system (Graphics and User's Exploration via Simple Sonics) that provides interrelational representation of objects in a nonvisual environment. And the stereo-vision system of Zelek's (Audette, 2000) group is added a feedback component, which is used to relay visual information via tactile feedback through the user's fingers. Another experimental vision substitution system for the visually impaired people, SoundView, also provides haptic feedbacks, and its effect is quite excellent (Doell, 2000).

Some of the 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, shown in "Figure 2.20" (top) 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 (Figure 2.20 bottom). 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 (Audette, 2000). 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.

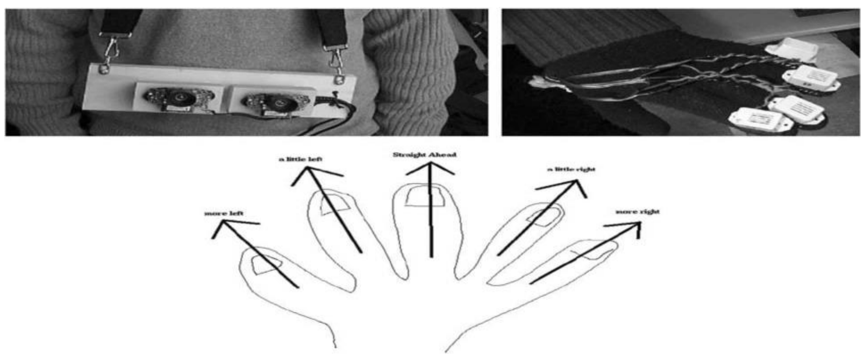


Figure 2.20 Prototype from the University of Guelph and the hand spatial correspondence.

Sainarayanan 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) (Figure 2.21) consists of a digital video camera, headgear (holds camera), stereo headphones, a single-board processing system (SBPS), rechargeable batteries, and a vest (that holds SBPS and batteries) (Sainarayanan, 2002).

The idea is that human's focus on objects that are in front of the center of vision and so it is important to distinguish between background and obstacles. The video camera captures grayscale video, which resembles 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 gray 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.

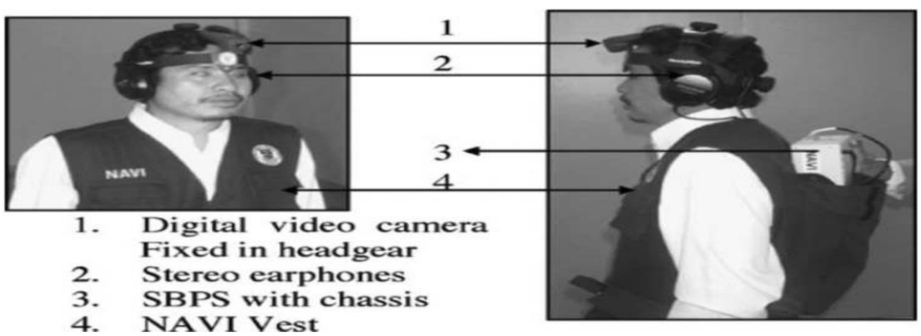


Figure 2.21 NAVI and its components.

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 consists of a sensor module with a detachable cane and a portable computer. The sensor (Figure 2.22) is equipped with two cameras, a keyboard (similar to those in cellphones), 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."(Hub, 2004)*

The computer contains software for detection of color, 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.

Concluding, 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, until this moment, limited simulated testing.

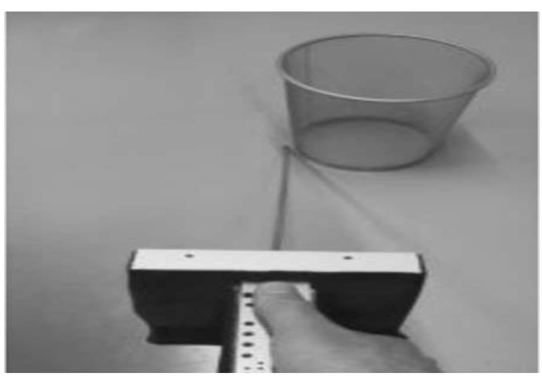


Figure 2.22 Sensor of the University of Stuttgart's project.

Although the blind users attain the capacity of some objects identification (e.g. black patterns on a white background) by the electro-tactile displays, they can not get hold of any available 3D perception during the mobility period which is needed for object recognition, spatial localization, target detection and obstacle avoidance. Due to these problems, a vision system for providing 3-D perception of the environment via transcutaneous electro-neural stimulation was developed by Simon Meers, Koren Ward, which is called as ENVS (short for Electro-Neural Vision System). It works by extracting depth information from the stereo cameras and conveying this information to the fingers via electro-neural stimulation. To interpret the range data, the user only imagine that his hands are being guided by fingers extended in the direction viewed by the cameras (Meers, 2004). The amount of electro-neural stimulation felt by each finger indicates the distance of objects in the direction of each of the fingers (as shown in Figure 2.23).

Figure 2.23 Electro-neural vision

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 (Figure 2.24) consists of two color microcameras 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, creates a depth map with attributes like distance, color, 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 (Gonzalez-Mora, 2004).

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.

Figure 2.24 Virtual acoustic space prototype (cameras and headphones mounted on eyeglasses and microprocessor) (right).

The electron-neural vision system (ENVS) by Meers (Meers, 2005) 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 (Figure 2.25) consists 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 (Meers, 2006).

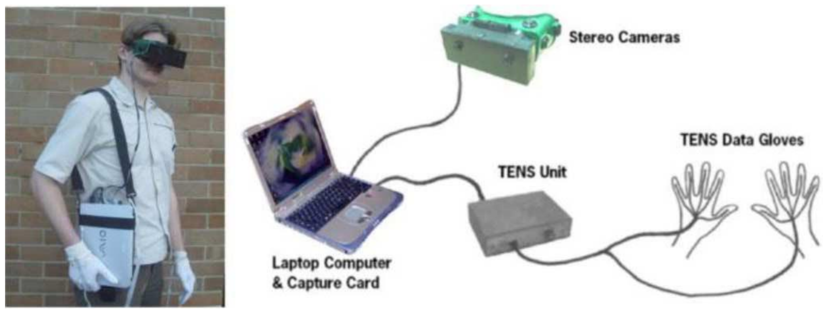


Figure 2.25 ENVS and its components.

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 hour) 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 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.

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) (Figure 2.26) and consists 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 (Johnson, 2006).

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 (Figure 2.27). 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, 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.

Figure 2.26 TVS prototype.

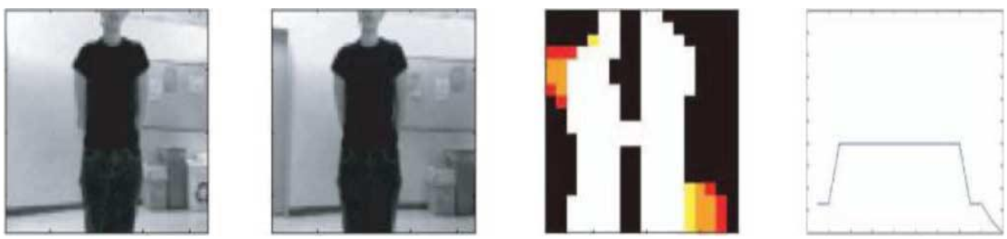


Figure 2.27: Example of TVS operation: image from the two cameras, disparity map, and the corresponding signals sent to the tactor belt.

Both sensor and camera are being used for some tresearch to detect the obstacle in front of the user.

Manduchi and Yuan 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 (Yuan, 2004). The system deals only with 1-D data, which is

Figure 2.28 UCSC’s handheld device equipped with laser range sensor.

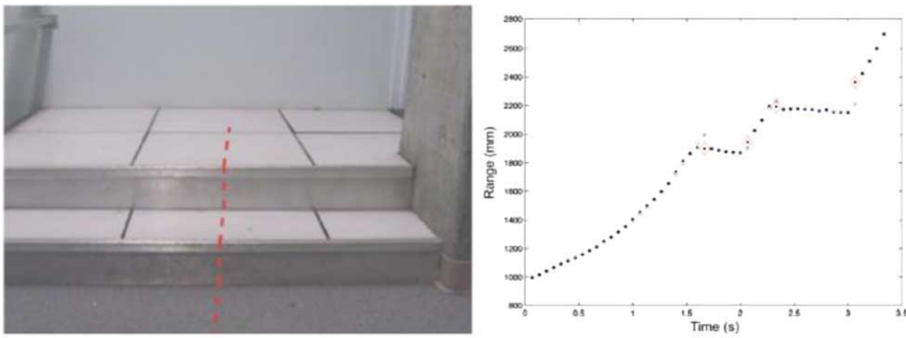


Figure 2.29 Time profile of two steps acquired as the device was pivoted in an upward motion.

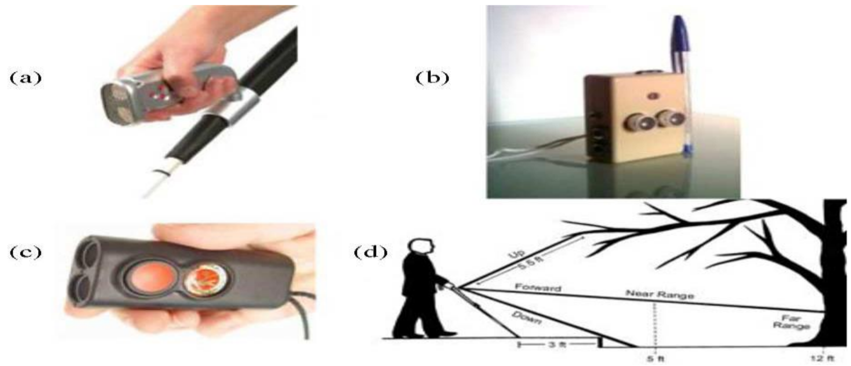


Figure 2.30 Commercial products: (a) K-Sonar Cane; (b) Mini-radar; (c) Miniguide; and (d) Laser Cane.

computationally cheaper than computer vision or spatial sound techniques. The prototype consists of a laser range sensor (point laser matched with a matrix CCD), as seen in “Figure 2.29”, and a computer. The rage sensor is based on active triangulation. In addition, the time profile of the range is analyzed by the computer to detect environmental features that are critical for mobility, such as curbs, steps, and drop-offs (Figure 2.30), 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; replacement of point laser with laser striper; built in processor in the device instead of computer; and tactile devices that will inform user about features detected.

Tyflos navigation system was conceived by Bourbakis and workers in the mid-1990s and various prototypes have been developed. The Tyflos navigation system consists of two basic modules: the Reader and the Navigator (ETA).

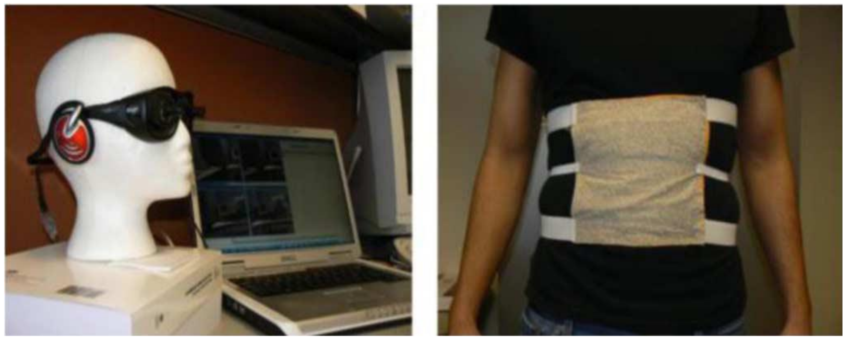


Figure 2.31 Tyflos' second prototype hardware components. Left: stereo cameras attached on dark eyeglasses, microphone, earphones, and portable computer. Right: 2-D vibration array vest attached on a user's abdomen.

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 (Dakopoulos, 2008).

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 manner. 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 is shown in “Figure 2.31”. It 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 (Figure 2.32).Optional audio feedback can inform the user for objects of interest.

The main advantages of the Tyflos are free-ear and the use of the 2-D vibration array with the variable vibration frequencies that offer the user a more accurate representation of the 3-D environment (including ground and head height obstacles) as well as 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.

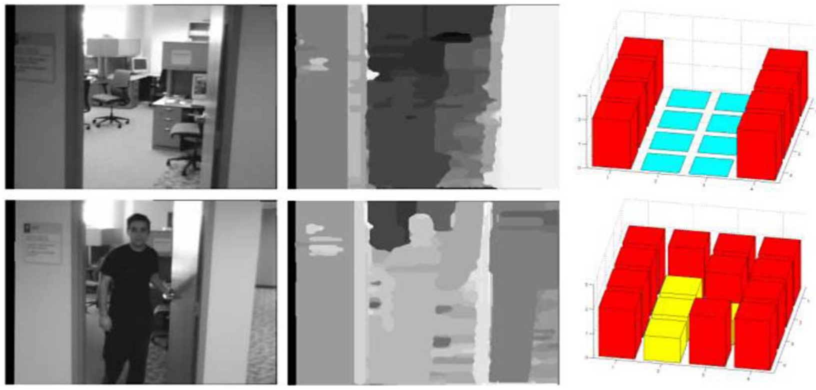


Figure 2.32 Operation of the Tyflos with two navigation scenarios (one in each row). Left column shows the images captured by the cameras; middle columns are the depth maps; right column is what the user senses via the 4 × 4 vibration array.

2.3 SUMMARY:

From the above survey, it becomes clear that, many researchers have worked for blind people to help them navigate their ways. Some of them used ultrasonic sensor, laser sensor or infrared sensor at different locations of the body for detecting front obstacles only; none talks about hazardous obstacle like step, stair or hole. Most of those systems are costly as well as need the huge power to operate and neither wearable nor hands free. Cameras have also been tried by some researchers to replace ultrasonics and the like sensors. However, for image processing it needs a computer or more sophisticated processing system which involves more cost and operating power and heavy weight. For conveying information about the surrounding, different actuating systems like sound, vibration, tactile force are used. Nevertheless, the problem of the blind people navigation with minimal dependency still remains unresolved due to less concern of the researchers about cost, weight, and power consumption of the blind navigation related devices. So the topic of blind people navigation still needs attention for better solution.

CHAPTER 3

DESIGN OF EXPERIMENTAL SETUP FOR TERRAIN DETECTION

3.1 Introduction

This chapter focuses on the design of experimental setup for detecting different obstacles on the way of a blind person. Selection criteria of the components of the experimental setup and their specifications are discussed in detail. Experiments on obstacles that are critical for blind navigation as for example holes, drop off, stairs down, stairs up and so on are conducted to come up with appropriate strategy in identifying them.

3.2 Design Guide Lines

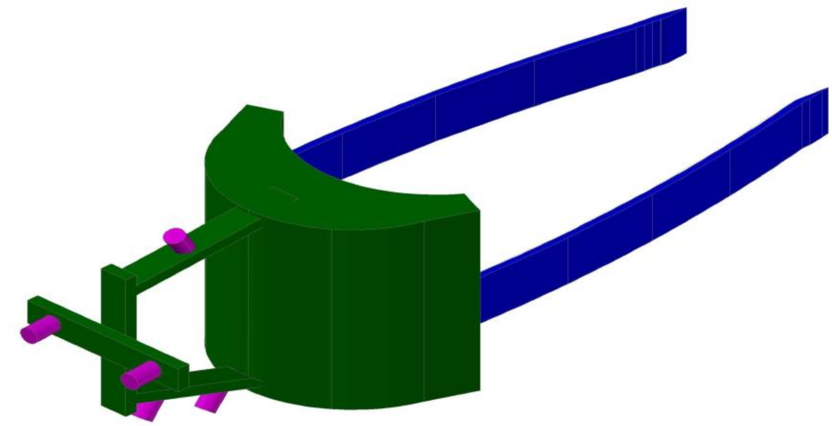
In the design process of the experimental setup it is assumed that the setup should be very similar to the prototype of the Walking Support System as demanded by the blind people, so that after finalizing strategy of identifying obstacles it can be converted into the prototype of the system. As such Malaysian Association for Blind (MAB) was consulted and the experimental setup, which later became the Walking Support System, was designed following their guide lines that are listed below:

- Cost: Affordable (around RM 500)
- Size and Weight: Less than 300gm
- Capability: Able to detect stair, hole, drop off etc.
- User friendly: Easy to learn the system
- Comfort: Does not need much change of current practice
- Hands free: Requires less involvement of hands
- Adaptable to all types of blind people(blind by birth, blind due to age or accident)

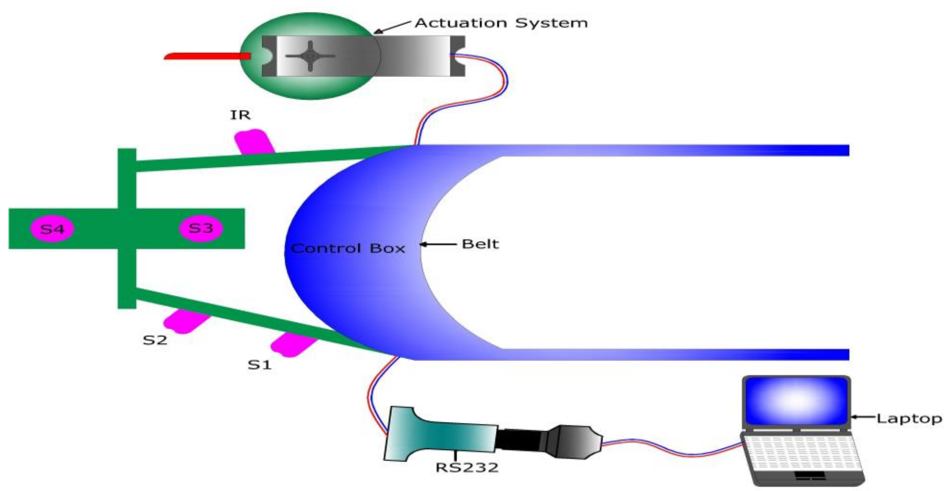
The National Research Council's (NRC) guidelines for ETAs [B. B. Blasch, 1997] are also taken into consideration in the design process. NRC guide lines are listed below:

1) Detection of obstacles in the travel path from ground level to head height for the full body width.
2) Travel surface information including textures and discontinuities.
3) Detection of objects bordering the travel path for shorelining and projection.
4) Distant object and cardinal direction information for projection of a straight line.
5) Landmark location and identification of information.
6) Information enabling self-familiarization and mental mapping of an environment.
7) In addition: ergonomic, operate with minimal interface with natural sensory channels, single unit, reliable, user choice of auditory or tactile modalities, durable, easily repairable, robust, low power and cosmetically accepted.

The experimental setup designed based on the above criteria is shown in Figure 3.1. It consists of a small Perspex structure whereon different sensors are mounted. A pouch of woven fabric is attached at the back of the Perspex structure to accommodate battery, microcontroller and all necessary circuitry. The pouch and the Perspex structure assembly is attached to a wearable belt around the waist of the user.



(a)



(b)

Figure 3.1 Experimental setup (a) isometric view showing orientation of the sensors on the supporting structure (b) actuator and data acquisition system attached to the wearable belt, S1, S2, S3 and S4 are the ultrasonic sensors.

List of the components used in the above system are as follows:

1. Belt with a pouch.
2. A supporting structure for placing sensors.
3. Ultrasonic sensors.
4. Sharp Infrared Sensor.
5. Servo Motor.
6. Micro Controller.
7. Micro Controller holder.
8. Buzzer.
9. RS 232 connector
10. Laptop.
11. Camera.
12. Battery.
13. LCD

3.2.1 Selection of Belt

This project emphasizes on the mobility of the blind user without having burdened with something that gives him a feeling that he is carrying some extra accessory. Belt is considered as a regular accessory of many individuals, as such it is expected feeling of new accessory will not arise. Besides that it can cater all other components that are selected for the experimental setup. It also help the user keep the hands free, i.e. the user does need to hold it by hand.

A belt is the most suitable design because the waist of a person somehow does not move a lot when walking compared to devices such as Smart Shoe, Smart Cane, SuperBat. SuperBat for instance, mounts the device on the cap of the user. The problem is that a head always move around, such as responding to a sound (Shoval, 1998). This will distract the ultrasonic sensor's directivity, thus disrupts the readings taken from the ultrasonic sensors.

3.2.2 Selection of Sensors

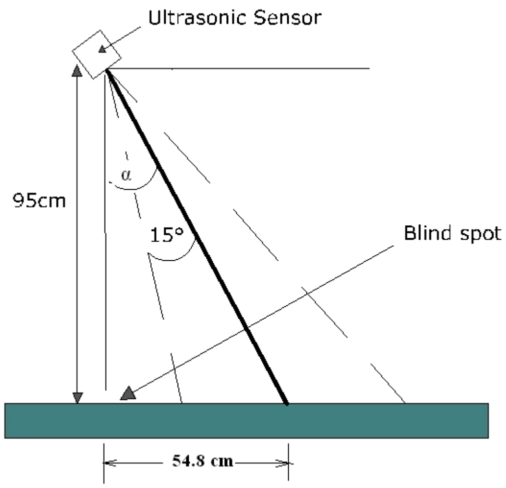
Sensors are the eyes of any blind support system. Ultrasonic sensors are widely used for it advantages over other sensors. One of the major advantages of ultrasonic sensor over camera is that it does not require light, whereas without proper lighting camera often captures images that are difficult to interpret. Ultrasonic sensor has drawbacks as well. Directivity of ultrasonic sensor sometimes provide with data, which mislead about the position or size of an object in front of the sensor. However, in this research we have managed to overcome this problem and decided to use four ultrasonic sensors for detecting obstacles like stair up, stair down, hole, wall in front, wall on left and right of a person etc. One sharp infrared (IR) is also used in this walking support system to detect over head obstacles. The main reason behind choosing IR sensor is its low price. IR sensor is not suitable for detecting obstacles around a person on the ground, as its range is low compared to ultrasonic sensor as well as affected by infrared radiations of different objects.

3.2.3 Ultrasonic Sensors arrangement.

The ultrasonic sensor detects objects by emitting a short ultrasonic burst and then "listening" for the echo. By using microcontroller, an input is given to the ultrasonic by using a trigger pulse. The ultrasonic sensor emits a short 40kHz ultrasonic burst. This burst travels through the air at approximately 344 ms^{-1}, hits an object and then bounces back to the sensor. The ultrasonic sensor provides an output pulse to the microcontroller that will determine when the echo is detected; hence the width of this pulse corresponds twice the distance to the target.

Figure 3.2 below shows the directivity of the sensor S1 or S2 while Figure 3.3 and Figure 3.4 show directivity of the front sensor's (S3 and S4) in their top view and end view. If the ultrasonic wave is not overlapping so there is no problem in determining which sensor is detecting an object. If the sensors are overlapping, a method called EERUF (Borenstein, 1991) has to be implemented so that it can determine which sensor is detecting an object. In the case of sensors arrangements used in this research the combined spread of the two front sensors are 40 cm, which is the width of an average man that appears about 55 cm away the man. This 55 cm distance is just equivalent to the distance of a stretched arm. Thus overlapping of sensor wave within this range does not need to be separated, because such overlapping actually indicates object is just in front of the user. Blind spot shown Figure 3.2 is not that significant, because while the user moves forward, an object enters the blind spot region only after it is detected in active zone of the sensors S1 and S2.

Ultrasonic



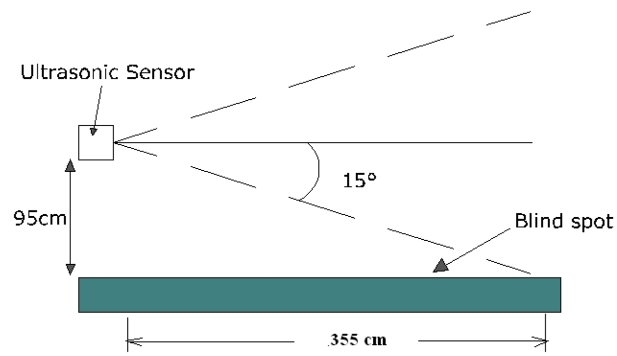


Figure3.2: Ultrasonic Sensor tilted at an angle with the vertical axis (α= 30°)

Figure 3.3: Ultrasonic Sensor directed parallel to the ground.

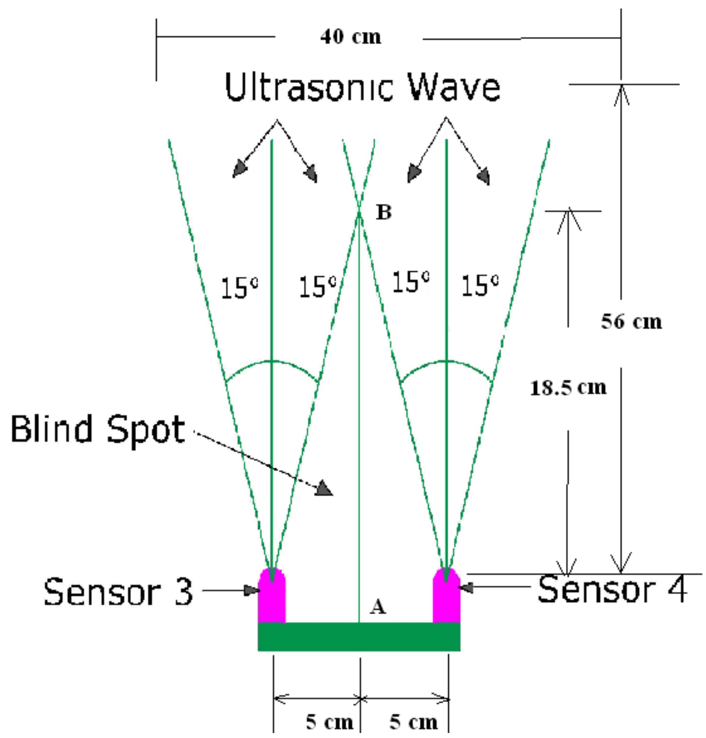


Figure 3.4 Directivity of ultrasonic sensor

3.3 Calibration of ultrasonic sensor for horizontal distance

In this experiment, the objective is to check the stability of the sensor's reading and verify the correctness of the distance of the user from the obstacle. The ultrasonic sensor is titled at an angle, so that the distance that the sensor is showing is the hypotenuse of a triangle as shown in Figure 3.5. So, we have used a method where an object is placed at a certain distance and the value of hypotenuse is taken from the ultrasonic sensor. Theorem Pythagoras is then applied to calculate the horizontal distance from the user to the obstacle (Figure 3.6). The actual horizontal distance is then measured to compare with the calculated distance. Comparison of the calculated and actual distances is as shown in **Table 3.1.**

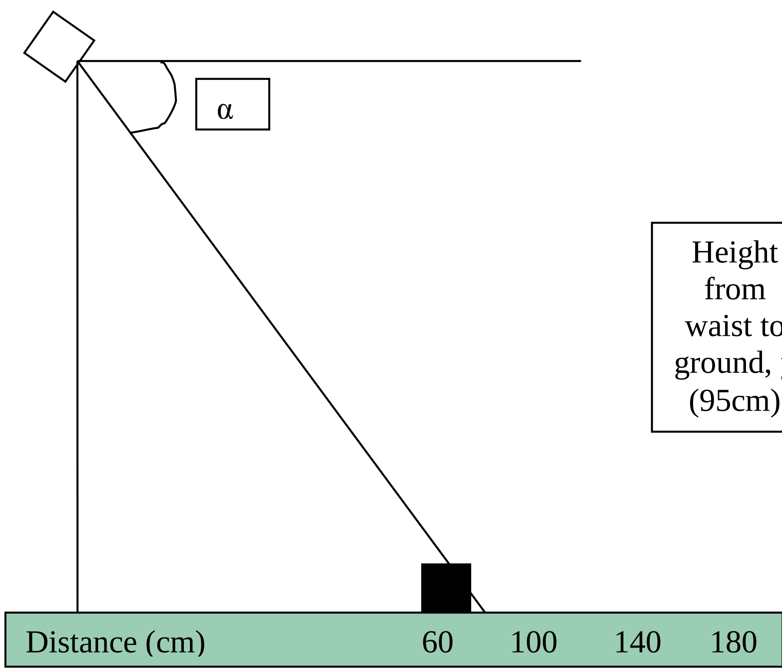


Figure 3. 5 Calibration of experiment

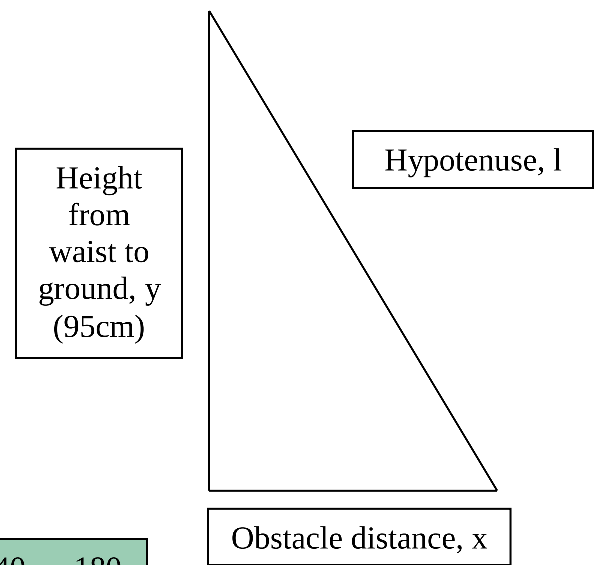


Figure 3.6 Theorem Pythagoras

Table 3.1: Calibration results for horizontal distance

Ultrasonic sensor Hypotenuse l (cm)	Obstacle Distance x (cm)	Calculated Obstacle Distance (cm) **$X= \sqrt{(l^2 - y^2)}$**	Percentage Error %
203	180	179.40	0.33
170	140	140.98	0.70
138	100	100.09	0.09
112	60	59.32	1.13

From the observation of the error shown in the above table it is seen that the error is about ±1 cm, which may be considered acceptable for the purpose of the walking support system measurements.

3.4 Sensor data on Flat Ground

After calibration of the ultrasonic sensors we conducted experiments with the sensors inclined at an angle with the vertical. The results of the sensors S1 and S2 (sensors shown in Figure 3.1) shown in Figure 3.7 show almost constant distance between the sensors and the ground. Evidently these are distances of the hypotenuses as shown in Figure 3.5. Thus we can conclude sensor reading for these sensors in the range of 35 to 40 inches means flat ground in front.

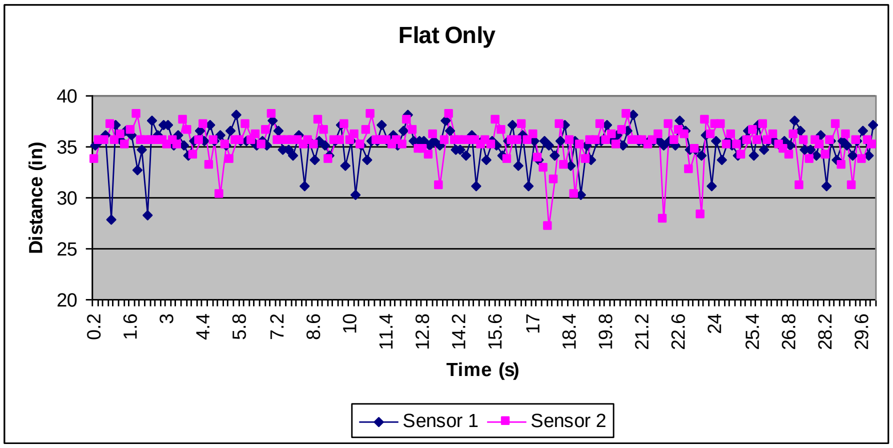


Figure 3.7 Ultrasonic sensor data read by sensors S1 and S2

Determining vertical height of an obstacle using ultrasonic sensor is a big challenge while the axis of the sensor is not perpendicular to the object. However, it is learnt from interview with the MAB that objects of small height and holes are among the worst type of obstacles for a blind person. In the following sections some experiments are presented which ultimately led to a method of detecting objects of small height as well as hole.

3.5 Experiments for Determining Height of an Obstacle

In this experiment, the objective is to determine the height of an object in front of the ultrasonic sensor that is attached to the waist of the user and pointing towards the ground at an angle. The setup for this measurement is shown in Figure 3.8 where the ultrasonic sensor is placed 95 cm above the ground and the axis of the sensor is inclined at an arbitrary angle of 35 degree with the vertical axis.

Two objects of respectively 12cm and 30cm height are used in this experiment. The procedure of calculating the object's height is as follows:

1. The object is placed at different horizontal distances from the user.
2. Length of the hypotenuse is read from the ultrasonic sensor data.
3. Calculate the angle using horizontal distance and the hypotenuse:

   $\Theta = \cos^{-1}$ (horizontal distance / hypotenuse)

4. Calculate vertical projection of the hypotenuse:

   H = hypotenuse (sin Θ)

5. Calculate the height of the object:

   h = *95cm – H

   *Vertical distance between the sensor attached to the waist and the ground.

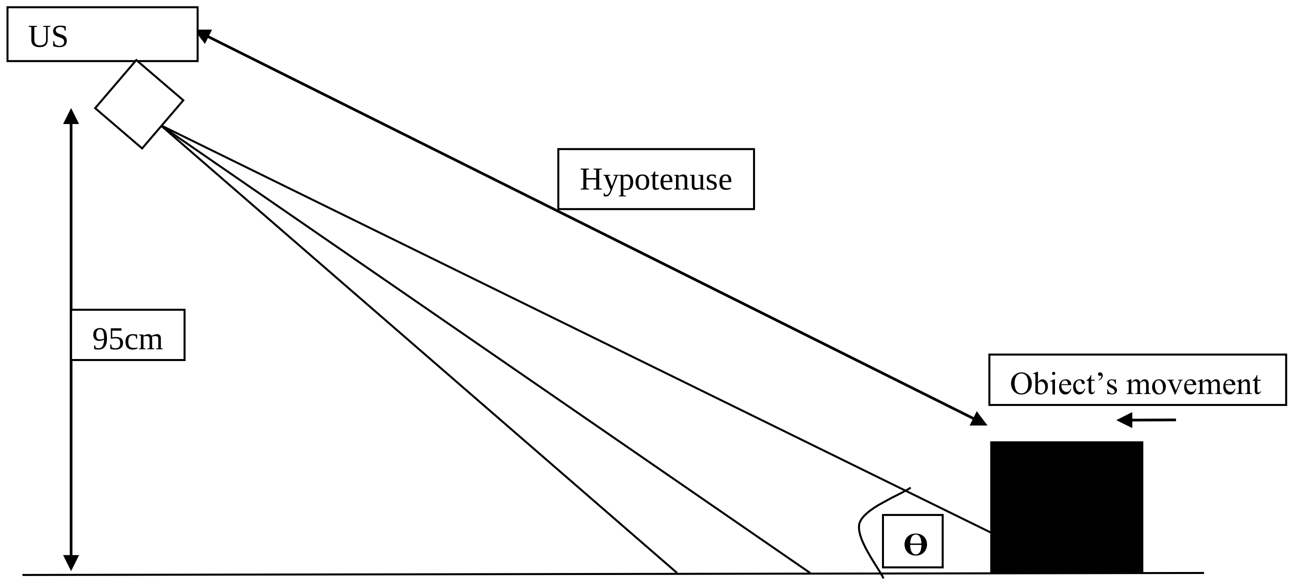


Figure 3.8 Experiment setup for detecting obstacle height

Table 3.2 Calculation for a 12cm high object using sensor data

No	Distance (cm)	Hypotenuse (cm)	Angle, **Ɵ** (degree)	Height H (cm)	Object's height h (cm)
1	200	222	24.4	92.8	2.2
2	190	212	26.3	93.9	1.1
3	180	203	27.3	93.8	1.2
4	170	194	28.8	93.4	1.6
5	160	186	30.7	94.8	0.2
6	140	168	33.6	92.8	2.2
7	120	153	38.3	94.8	0.2
8	100	138	43.6	95.7	-0.7
9	80	124	49.8	94.7	0.3

Table 3.3 Calculation for a 30cm high object using sensor data

No	Distance (cm)	Hypotenuse (cm)	Angle, Θ (degree)	Height H (cm)	Object's height h (cm)
1	200	221	25.2	95.1	-0.1
2	190	212	26.3	93.9	1.1
3	180	203	27.5	93.7	1.3
4	170	195	29.3	95.4	-0.4
5	160	185	30.1	92.8	2.2
6	140	168	33.3	92.2	2.8
7	120	153	38.3	94.8	0.2
8	100	138	43.6	95.2	-0.5
9	80	124	49.8	94.7	0.3

From Table 3.2 and Table 3.3, it is observed that the above experiments failed to estimate heights of the objects. From the calculated values of θ, shown in the fourth column of table 3.2 and 3.3 it is evident that directivity of the ultrasonic sensors is the main cause of this failure of predicting height of objects in front. However, gradual decrease of hypotenuse distance is an indicator of objects of different height above the flat land in front of the sensors S1 and S2. This is confirmed through repeated experiments with different objects.

3.6 Experiment for detecting Hole in front

A hole on the walk way being a critical obstacle, we conducted experiments with our system for detecting a hole. In the case of a hole in front, it is expected that sensors S1 and S2 are going to give readings of values more than 40 inches (readings for flat land is 35 to 40 inches, shown in Figure 3.7), however, the data set shown in Figure 3.8 shows no difference between flat land and a hole. We can infer from this experiment that sensor data for these two sensors while detecting stairs down should also show similar trend.

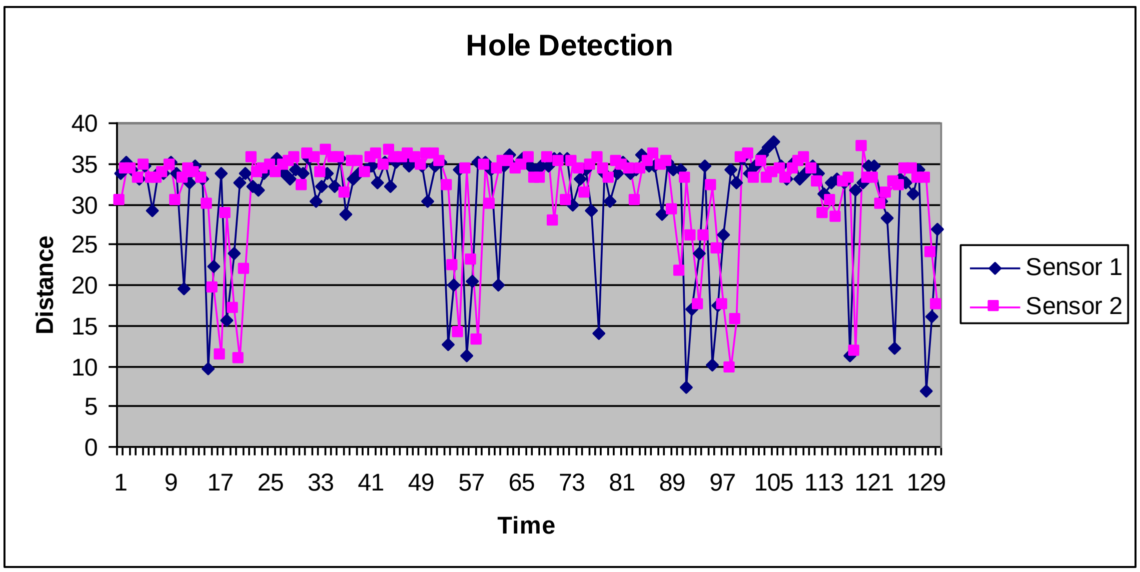


Figure 3.9 Hole detection

It is learnt from the MAB interview that holes and stairs down are the most critical among all other obstacles for a blind person. Failing to detect these terrain data, we made a mathematical model of these scenarios to identify causes of failure which is shown in the next section.

3.7 Mathematical Model

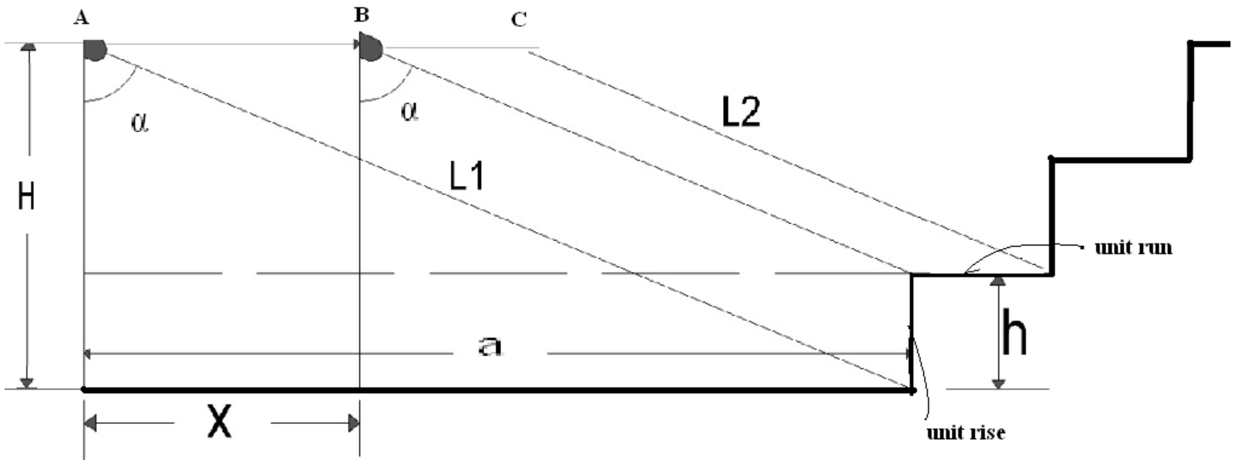


Figure 3.10 Geometry of stair up for sensor data read by sensor S1 or S2

In Figure 3.9 shown above let the stair be at a horizontal distance, 'a' from the user while the root of the stair is at a distance of L1 measured by the ultrasonic sensor S1, where the sensor is inclined at an angle, α with the vertical axis. Let the sensor be at locations A and B while the ultrasonic wave hits the root and tip of the 1st unit rise, and be at C while it hits root of the 2nd unit rise. During this course of movement of the sensor from position A to B it travels a distance X. This can be expressed as shown in Equation 3.1:

$$X = h \tan \alpha \qquad 3.1$$

Also we can write

$$a = H \tan \alpha \qquad 3.2$$

Now if it is assumed H = 30 in , a = 30 in (almost equal to three steps of walking)

Then eqn. 3.2 gives $\alpha = 45^o$

On substituting this value of α in eqn. 3.1 we get $X = h$

A standard unit rise of a stair is around 7.75 inch.

For a normal human, walking speed 'v' is about 40 in/s. Let the walking speed of a blind person be half of a normal human. Then for a blind person it would be around 20 in /s. In that case time taken to move distance X is:

$$t = X/v = h/v = 7.75/20 = 0.39 \text{ s}$$

Resolution of ultrasonic our ultrasonic sensor is 50 ms. As such during one second interval we can get 20 data maximum. So during the travel of X inches distance, number of data one sensor will be able to read is 20x0.39 = 8 (approx.). From equation 3.1 we can see with increase of α the distance X increases. That means number of data could be increased using larger angle.

However, from Figure 3.10 we see as the angle α increases only a small portion of a hole is hit by ultrasonic wave, thus the length 'c' remains undetected. Following the geometry of Figure 3.10 we can write:

$$C = h \tan \alpha \qquad 3.3$$

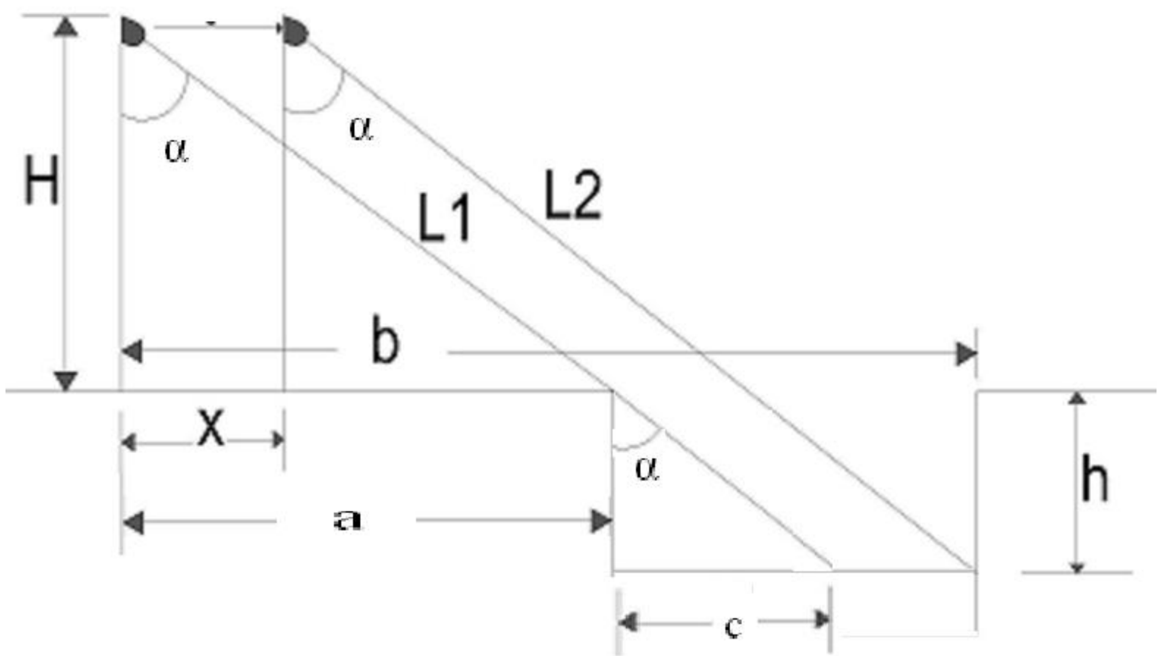


Figure 3. 11 Geometry of hole for sensing data by sensor S1 or S2

Let us assume c = 3 inches and h = 6 inch

Then eqn 3.3 gives $\alpha = 26.56^o$

Using this value of α in eqn. 3.2 we get $a = 30x \tan 26.56 = 15$ inch.

This distance is almost 1.5 step of a man. Now if we assume width of a hole is equal to 7 inches, which is just little bit smaller than one foot length. Then the distance traveled to sweep the hole is x = 7-3 = 4 inches.

To move this distance a blind person will take time t = 4/ 20 = 0.25 second. During this time, number of data read by the sensor will be equal to = 20*0.25 = 5.

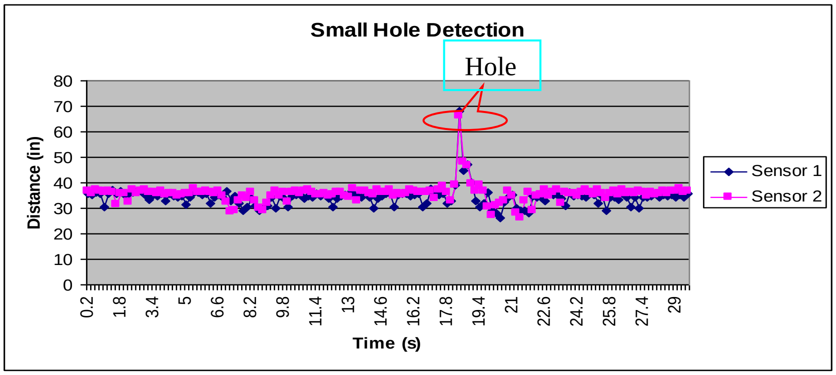
From the above mathematical analysis it is clear, in detecting hole we have to use smaller angle.

Thus there arises a conflicting situation for detecting stair up and hole. Hole can be considered equivalent to stair down. In this conflicting situation we can have a compromise where α can be set equal to 30^o. This will give 5 data in case of a stair up and 4 data in the case of hole or stair down.

3.8 Success in detecting hole

Based on the above mathematical model sensors S1 and S2 are placed at 30^o with the vertical. This new orientation of the sensors helped in identifying hole ahead that are shown in Figure 3.11 (a) and (b) respectively. Number of data at the hole is found to be quite low as predicted by the mathematical model.

(a)



(b)

Figure 3.12 (a) Photograph showing hole in front. (b) Hole detected with sensors S1 and S2 inclined at 30^o with the vertical axis.

3.9 GUI Development

We have developed a GUI for data acquisition from the environments through the sensors using visual C program. During the experiment data is sensed by the sensors attached to the Belt for Blind system, where the sensors are interfaced to a laptop through microcontroller and RS232 connector. The laptop has data logger to store data from all the sensors. Later we have used those acquired data for plotting graphs to detect different obstacles on the walkway of the experimenter.

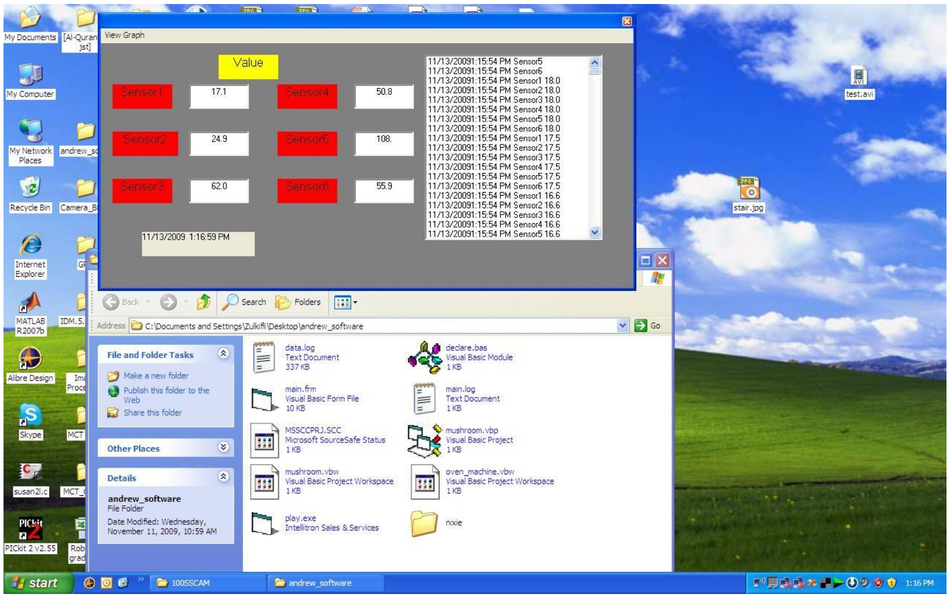
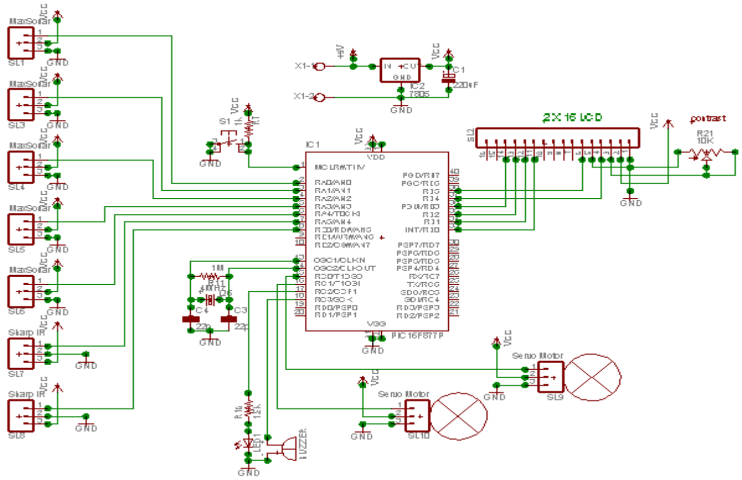
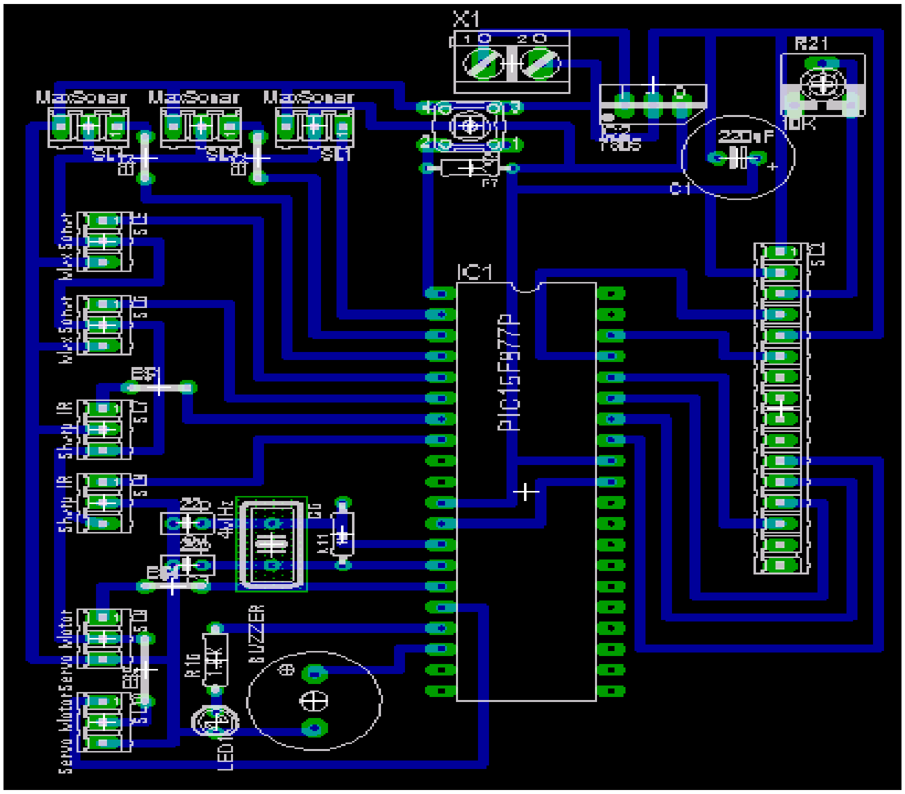


Figure 3.13 GUI screen shows sensors and data

The circuital diagram has been shown here, which consists of four ultrasonic sensors, one sharp infrared sensor, micro-controller, buzzer, servo motor, LCD and so on.



(a)



(b)

Figure 3.14 (a) Circuit diagram of the system (b) PCB layout of the circuital diagram

3.10 Summary

This chapter developed instrumentation for acquiring terrain data. Here a mathematical model is developed to identify why researchers fail to detect critical obstacles like stair and hole. Based on the outcome of the mathematical model appropriate orientation of sensors and pace of a user have been recommended. In the next chapter extensive experiments are conducted to identify various obstacles for mapping obstacle environment around a blind user.

CHAPTER 4

TERRAIN DETECTION EXPERIMENT AND DATA ANALYSES

4.1 Introduction

This chapter presents experimental data on different terrain and their analyses. Experiments conducted for terrain detection mainly ueses the sensory system designed and developed in chapter 3, and concentrates on critical obstacles like stairs up, stairs down, drop off, overhang etc. These obstacles are considered as critical for the blind people following an interview with MAB personnel.

4.2 Stair Down

Stair case is a part and parcel of a building. Almost everybody needs to use stairs few times every day. People with visual capability may not feel the difference between climbing up and going down a stair case. However, to a blind person this difference is very significant, especially a stair down needs detection before he needs to step on to the stair, otherwise serious accident may happen to the extent that causes death of the person. In Figure 4.1 before the detection of the edge of the stair, reading from both the sensors that are pointing toward the ground (S1 and S2) remians within a band of 35 to 40 inch. As soon as the soundwave from these sensors clears the edge of the beginning of the 1st step downward it will hit the next step which is at a lower level than the 1st one, as such readings of the sensors S1 and S2 must suddenly increase, whearas readings of sensors S3 and S4 will remain unchanged . In Figure 4.1 data marked against detection of stair down is quiet distinct. From repeated experiments with steps of height 9 inches this data ranges between 45 to 52 inches for sensors S1 and S2.

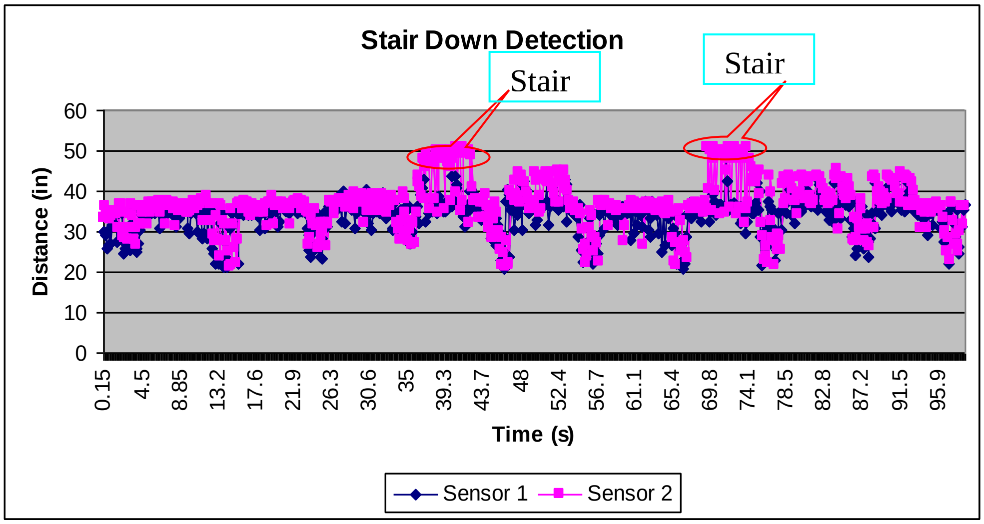
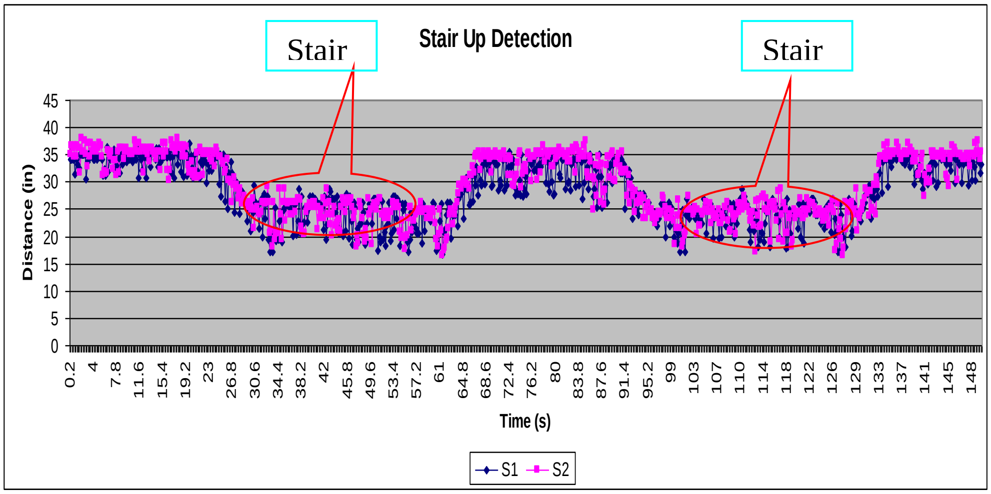


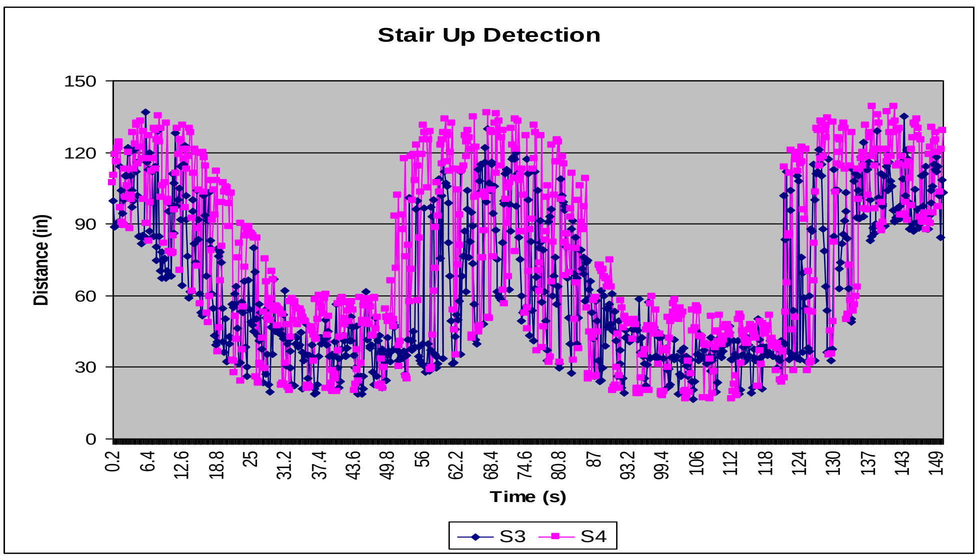
Figure 4.1 Data showing beginning of a step leading toward down stair

4.3 Stair up

Stair up though is the reverse of stair down, however, is not as critical as stair down. In the case of detection of such stairs all the four ultrasonic sensors show lower values relative to those shown while the person is moving on a flat surface. Through repeated experiments it is found that sensors S1 and S2 give readings less than 35 inches while sensors S3 and S4 show reading less than 60 inches.



(a)



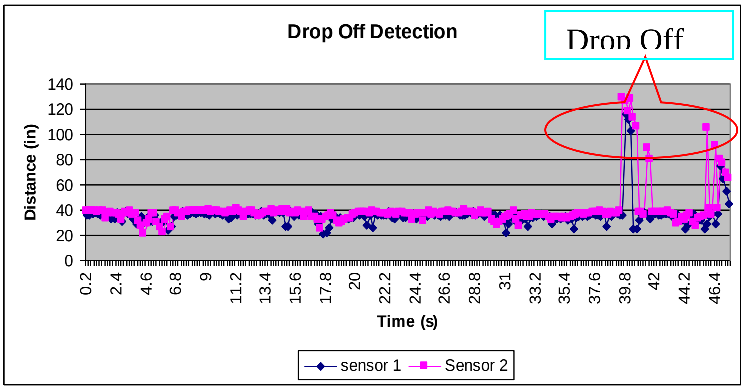
(b)

Figure 4.2 Sensor data during climbing a stair upward

4.4 Drop Off

Drop off is a critical obstacle like that of stair down. Drop off may appear in three different ways say (1) in front of a person and (2) on the left as well as (3) right side of a person. Figure 4.3(a) shows photograph of drop off in front of a person while Figure 4.3(b) shows readings of sensors S1 and S2 both on the flat surface before the drop off begins and on the brink of drop off. Readings of the sensors S3 and S4 remains unchanged. In this case the drop off being very deep, readings at the brink of the sensors are found to be more than 100 inches. However, this reading would depend on the depth of the drop off. Thus to differentiate drop off from stair down we have chosen readings of both sensors S1 and S2 more than 55 inches at a time as drop off. This value is slightly higher than that for stair down.

(a)



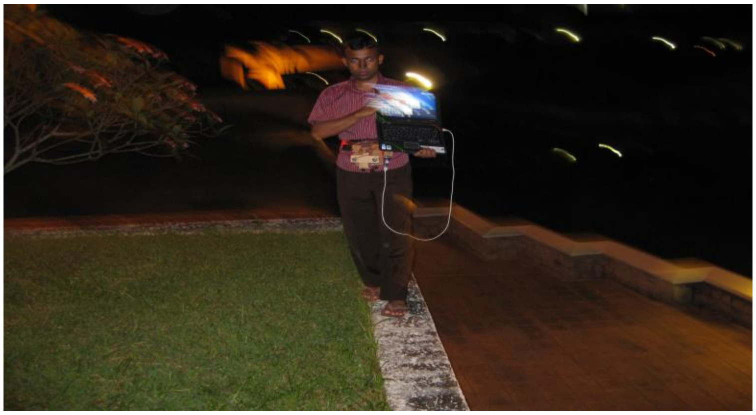
(b)

Figure 4.3 (a) Photograph of drop off in front of a person (b) Sensor data on flat surface and at drop off.

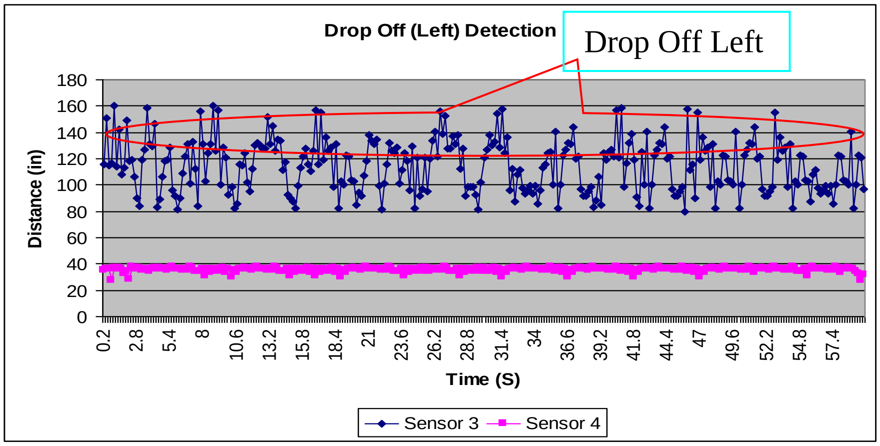
In Figures 4.4(b) sensor S1 shows high values of data while sensor S2 shows data corresponding to flat surface. The scenario that provides this data is shown in Figure 4.4(a), which is the photograph showing drop off on the left side of a person. Similar scenario with drop off on the right side gives higher value of data at sensor S2 and lower value at sensor S1. This is depicted in figure 4.5. Comparing data for drop off on the left and right sides with the data of drop off in front we have chosen following criteria for identifying these scenarios.

Drop off on left: S1 reads more than 55 inches while S2 reads less than 40 inches, and S3, S4 remains unchanged.

Drop off on right: S2 reads more than 55 inches while S1 reads less than 40 inches, and S3, S4 remains unchanged.



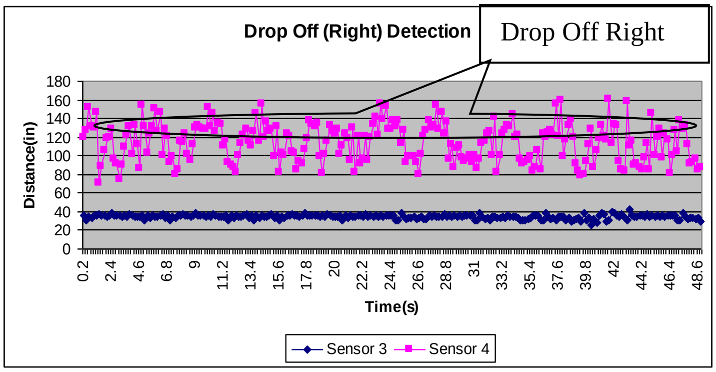
(a)



(b)

Figure 4.4 (a) Photograph showing drop off on the left side of a person (b) Sensor data shown by sensors S1 and S2.

(a)

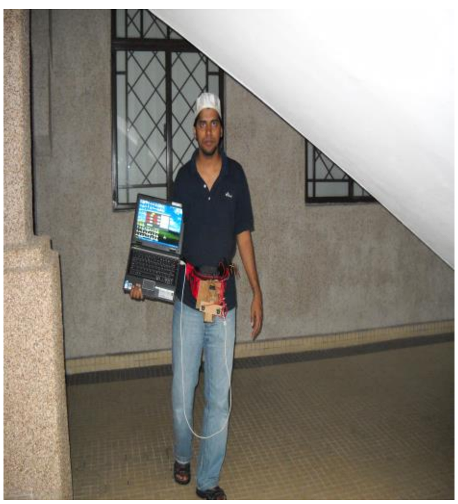


(b)

Figure 4.5 (a) Photograph showing drop off on the right side of a person (b) Sensor data shown by sensors S1 and S2.

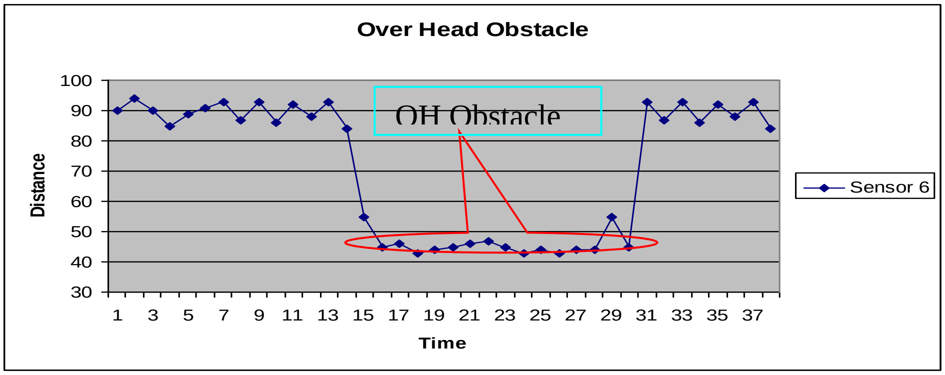
4.5 Over Head Obstacle

A blind man generally carries a white cane to scan obstacles at the ground level. Thus, over head obstacle is only detected when his head hits against such obstacle. In this research, to take care of this type of obstacles, a sharp IR sensor is attached to the belt facing upward direction making an angle with a line perpendicular to the ground. This arrangement help detect over head obstacles before hitting the obstacle. Two different types of such obstacles are shown in Figure 4.6 (a) and (b), and corresponding sensor data is shown in Figure 4.6(c). Assuming a clearance of 12 inches above the head the distance of an over head obstacle from the IR sensor on the belt at waist level can be about 50 inches. Therefore, less than 50 inches reading of the IR sensor is considered as over head obstacle.



(a)

(b)



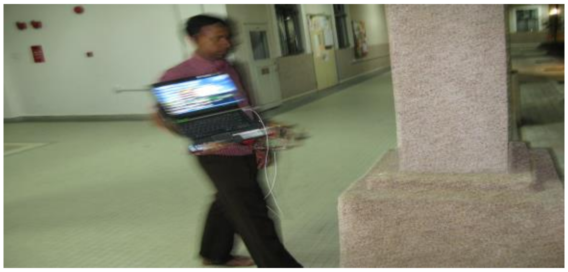
(c)

Figure 4.6 (a) Photograph of a slanted over head obstruction (b) Photograph of an over head obstruction coming out of a wall (c) Sensor data showing detection of over head obstruction.

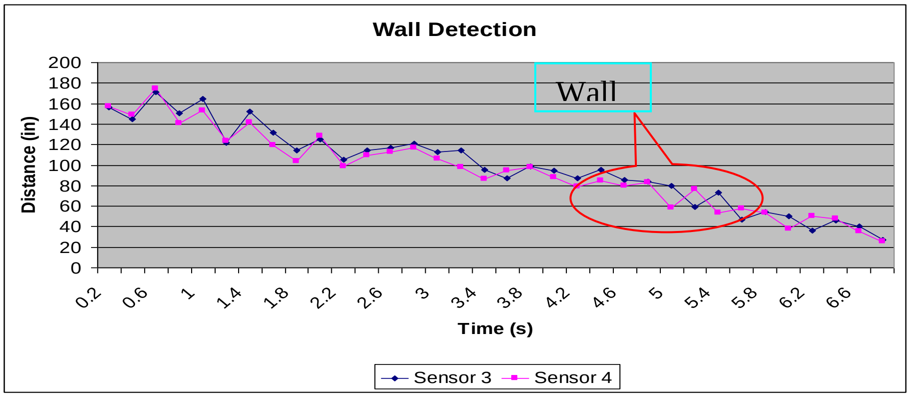
4.6 Wall/Front Obstacle

Walls and pillars are the common obstacles both indoor and outdoor. Two such photographs are shown in Figure 4.7(a) and (b). It is obvious readings of the sensors S3 and S4 will be decreasing once such obstacles are detected. Once readings of both the sensors show less than 25 inches, it will be considered obstacle in front of the person. In such a situation a blind person will have the option to move left or right to confirm nature of the obstacle, say wall or pillar.

(a)



(b)



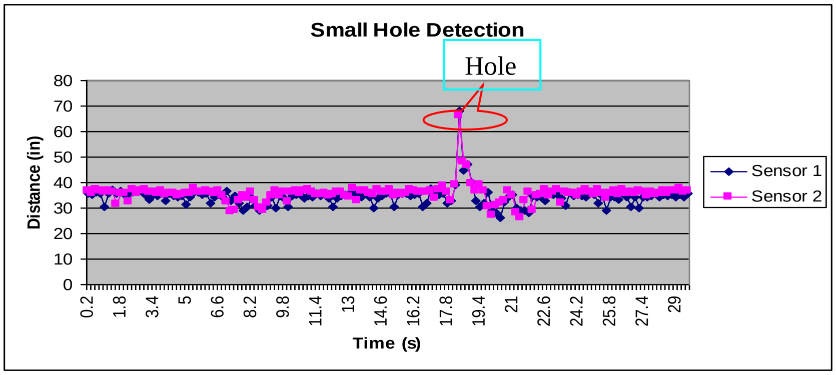
(c)

Figure 4.7 (a) Wall in front of a person (b) Column in front of a person (c) Sensor data shown by sensors S3 and S4.

4.7 Hole in front

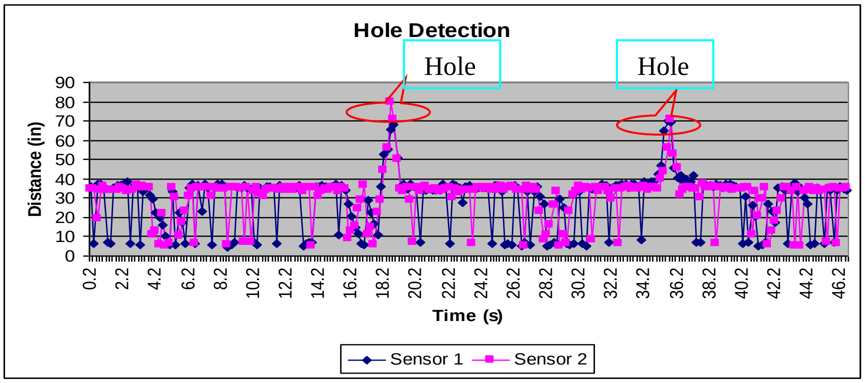
Holes are common obstacles on walk ways. In Figure 4.8 (a) and (b) photographs of a small hole, and corresponding data read by the sensors S1 and S2 are shown. Unlike drop off in front, in the case of a hole high value of data appears for a very short duration. In the current state of the hardware developed for terrain detection, we put this scenario in the category of drop off in front. However, it is expected that proper training of a blind person will make him feel the difference between drop off in front and small hole in front.

(a)



(b)

(c)

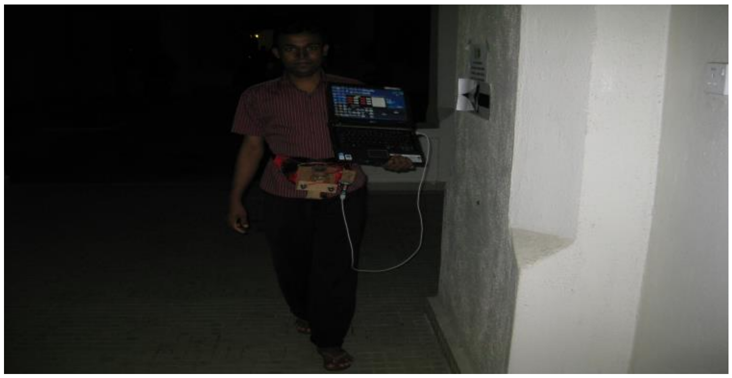


(d)

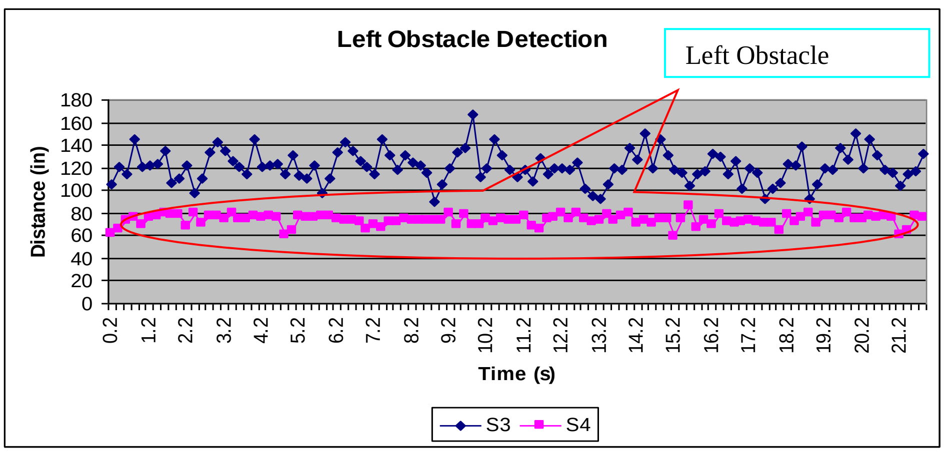
Figure 4.8 (a) Photograph of a hole in front of a person (b) Sensor data shown by sensors S1 and S2 (c) Photograph of a double hole in front of a person (d) Sensor data shown by sensors S1 and S2.

4.8 Obstacle on Left or Right

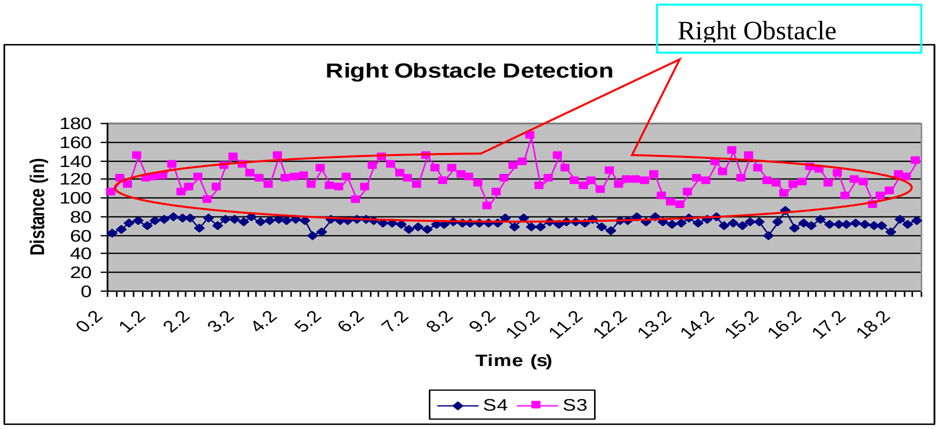
Obstacles either on the left or right are also common scenarios. Trend of data read by the sensors S3 and S4 in these two scenarios are shown in Figures 4.9(b) and (c) respectively.



(a)



(b)

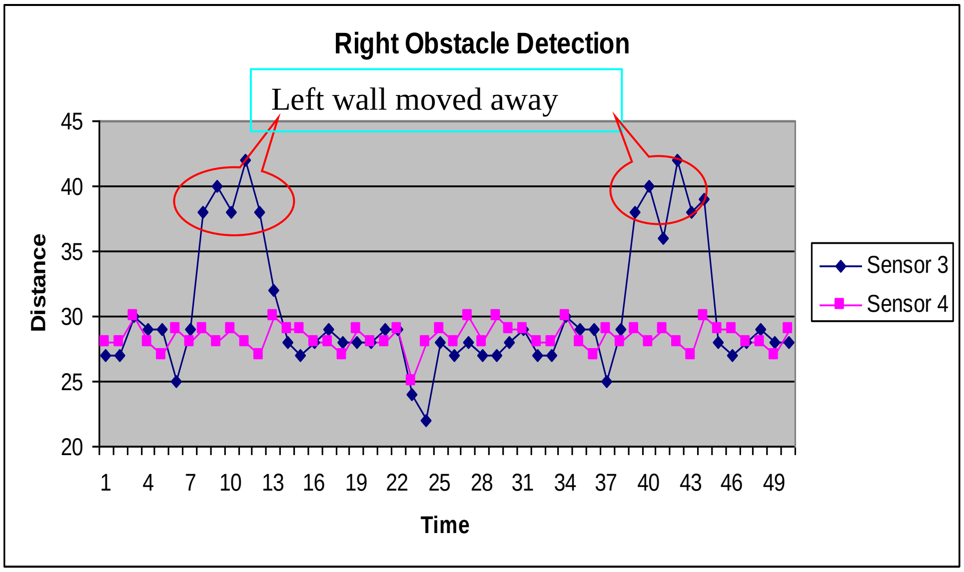


(c)

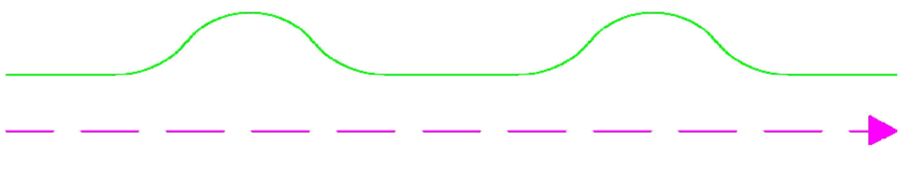
Figure 4.9 (a) Photograph of obstacle on the left side of a person. (b) Sensor data detecting obstacle on left side. (c) Sensor data detecting obstacle on right side.

4.9 Complex Scenario

In real life it is rare that all scenarios will appear as discrete maps as experimented above. In Figure 4.10(a) sensors S3 and S4, which are directed parallel to the ground, are showing readings of lower distances that remain constant for significant time. This is a scenario where the user is passing through a passage between two walls maintaining almost equal distance from the walls. At two locations suddenly sensor S3, which is located toward left, shows higher distances. Left wall actually moved a bit away from the right wall. Such a scenario needs actuation data to the user from two different actuators as well as training of the user. The sketch of the scenario is shown in Figure 4.10 (b).



(a)



(b)

Figure 4.10 (a) Sensor data showing complex scenario. (b) Sketch showing complex scenario.

4.10 Image Processing

Besides the above experiments we also tried image processing on photographs taken by digital camera for detecting Stair and Hole. The only feature of stairways is that their profile includes a set of parallel lines in 2D space, however, for holes there is no proper specification without depth or edge detection.

The intention of our vision algorithm is to detect long, horizontal lines in an image, and to extract the most similar ones among these lines which should be the stair edges. Figure 4.11 illustrates the whole flow of our algorithm.

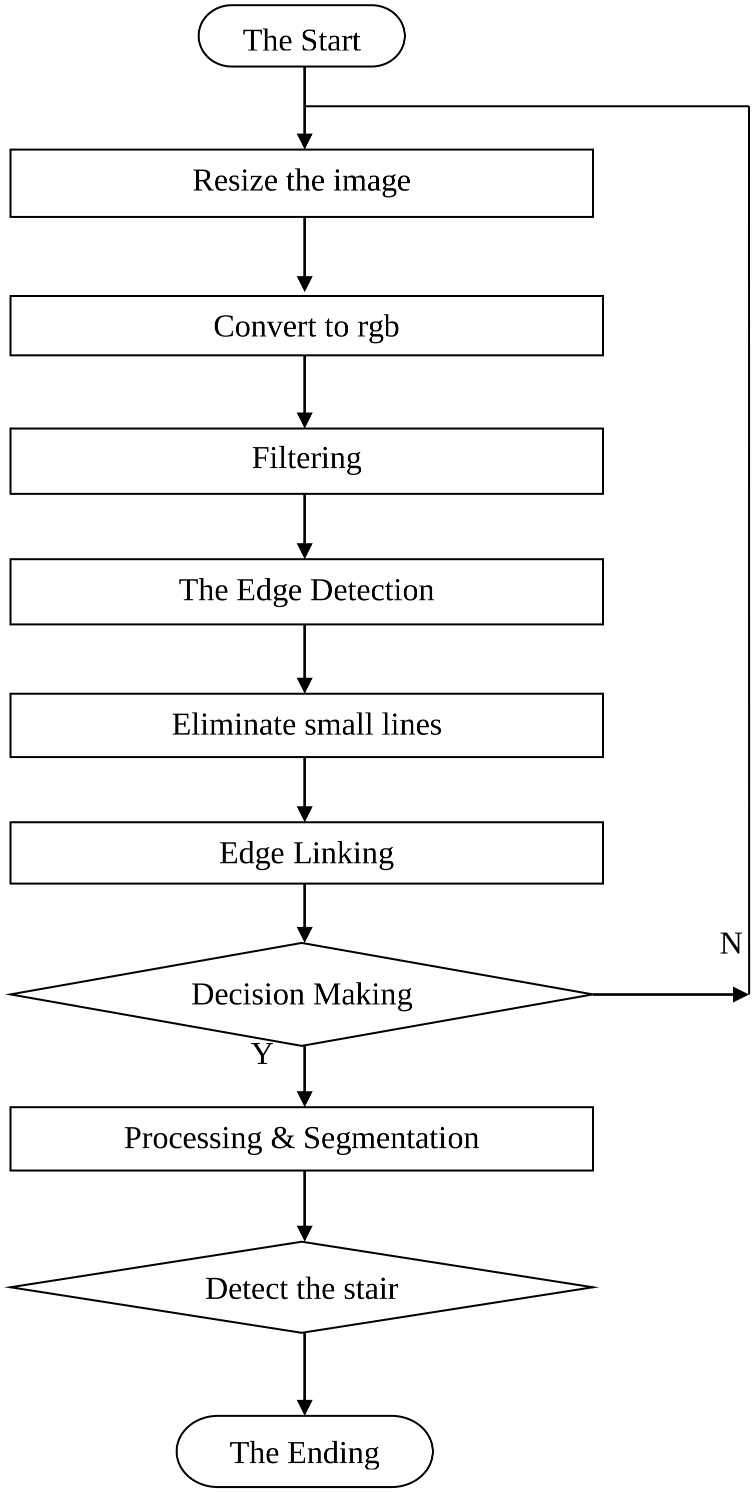


Figure 4.11: The Whole flow of our algorithm

Our algorithm includes the following steps:

Firstly, resizing of the original image is done before the Gaussian function is used to filter the image. We convert this image into rgb scale in order to eliminate the influence of the illumination retaining the stair edges. Secondly, the prewit as well as canny edge detectors are applied to the filtered image. With our proposed fast algorithm the most of the small, vertical edges are removed. It can improve the efficiency and accuracy of the linking algorithm in the next step. Thirdly, the remainder adjacent edges are linked into long, horizontal edges (which should be the stair edges) according to some basic constraints. Finally, we can make a decision about stair ahead. However, it is very difficult to differentiate whether it is stair up or stair down. Photographs of stairs up and down are shown in Figures 4.12 and 4.14 respectively, and their processed images for edge detection are shown in Figures 4.13 and 4.15 respectively.

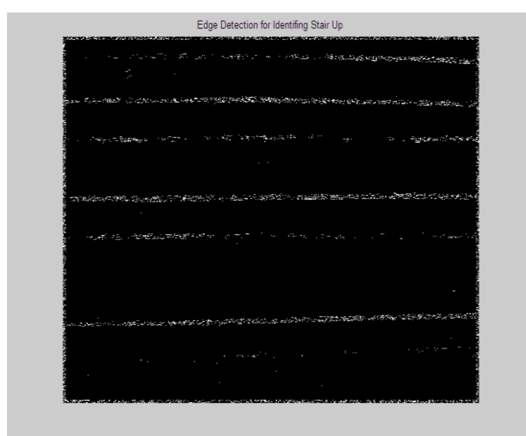


Figure 4.12: Original Image stair up

Figure 4.13: Extracting parallel stair up edges

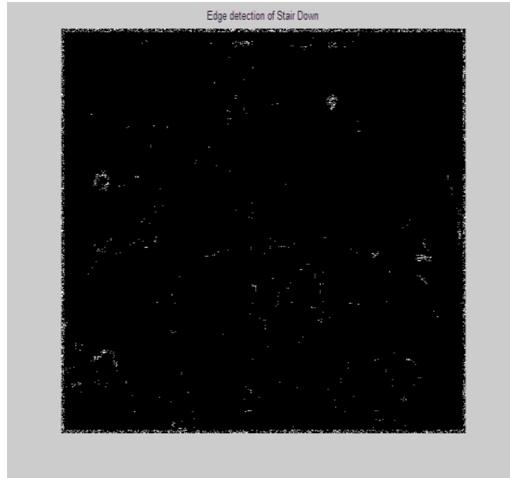
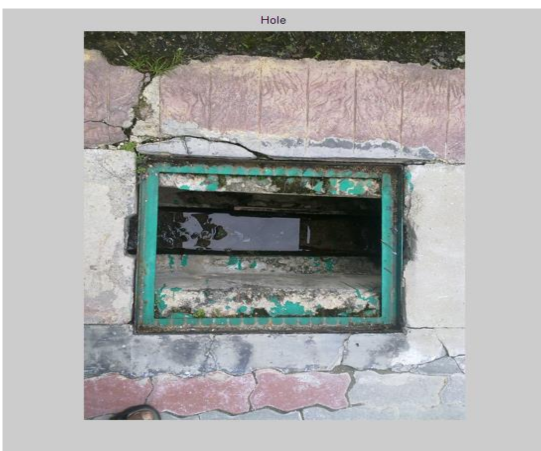


Figure 4.14: Original Image stair down **Figure 4.15**: Extracting parallel stair down edges

Photograph of a hole and its processed image are shown in Figures 4.16 and 4.17 respectively. It is clearly evident in Figure 4.17 that the there is no depth information available in the processed image that could lead to identification of the hole.



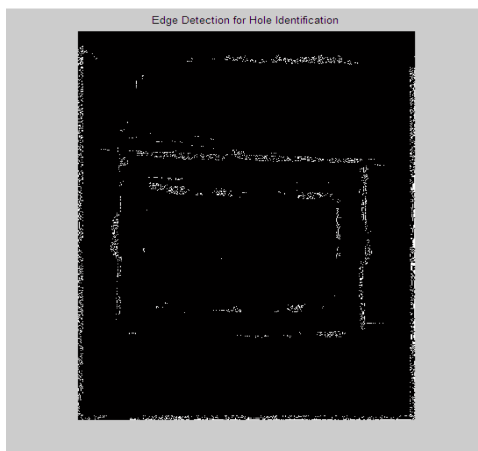


Figure 4.16: Original Image for hole **Figure 4.17**: Extracting hole edges

Besides the difficulty of identification, image processing also takes time and requires huge memory. As such we resorted to ultrasonic sensors for detecting terrain around a visually impaired person.

4.11 Summary

This chapter analyzed trend of ultrasonic sensor data for critical obstacles, like stair up, stair down, hole, different types of drop offs and so on. From the above analyses distinguishing features have been identified which are later compiled in the form of flow chart as well algorithm in the following chapter for developing blind support system hardware.

CHAPTER 5

ALGORITHM AND HARDWARE DEVELOPMENT

5.1 Introduction

This chapter compiles information gathered through experiments in chapter 4; and based on the information, develops flow charts and algorithms for identifying types of obstacles on the walkway of a blind person. Here the blind support system hardware is put in its final shape integrating actuating system, sensing system and software.

5.2 Classification of Obstacle Type

In the previous chapter we have presented experimental results on trends of sensor data against different types of obstacles. In Table 5.1 data off all the 5 sensors used in the experiments are put in 5 columns against the name of the obstacles shown in column one. In column two of this table, obstacles are classified with numerical designations, and the column is shown in bold face. Thus nine different types of obstacles are being represented through their respective sets of sensor data.

Table 5.1 Obstacle classification based on sensor data

Obstacle Name	**Obstacle Type**	Servo Position in degree	Sensor 1	Sensor 2	Sensor 3	Sensor 4	Sensor 5
Over Head	**1**	20	0	0	0	0	Less than 50
Stair Down	**2**	40	More than 45 Less than 52	More than 45 Less than 52	0	0	0
Hole/ drop off in front	**3**	60	More than 55	More than 55	0	0	0
Stair Up	**4**	80	Less than 35	Less than 35	Less than 60	Less than 60	0
Wall	**5**	100	0	0	Less than 25	Less than 25	0
Front Left	**6**	120	0	0	Less than 15	Less than 35	0
Front Right	**7**	140	0	0	Less than 35	Less than 15	0
Drop off_ Left	**8**	160	0	0	More than 55	Less than 40	0
Drop off_Right	**9**	180	0	0	Less than 40	More than 55	0

5.3 Actuator System Design

The main goal of this research is to design and develop a blind support system that would help visually disabled people walk smoothly. In this respect we need proper actuating system to be incorporated with the sensing system through software. A sevomotor with an indicator needle attached to its rotor as shown in Figure 5.1 is selected as the actuating mechanism for conveying the information to its user. Based on the scenario mapped in table 5.1, the servomotor will show 9 positions. The servomotor assembly is attached to the pouch on the Belt for Blind. On top of that a buzzer is also attached to this system. The moment an obstacle is detected, the buzzer will beep and the needle will move to a position corresponding to the type of the obstacle detected. On touching the dial after hearing the beep the user will be able to identify type of the obstacle and accordingly plan his move.

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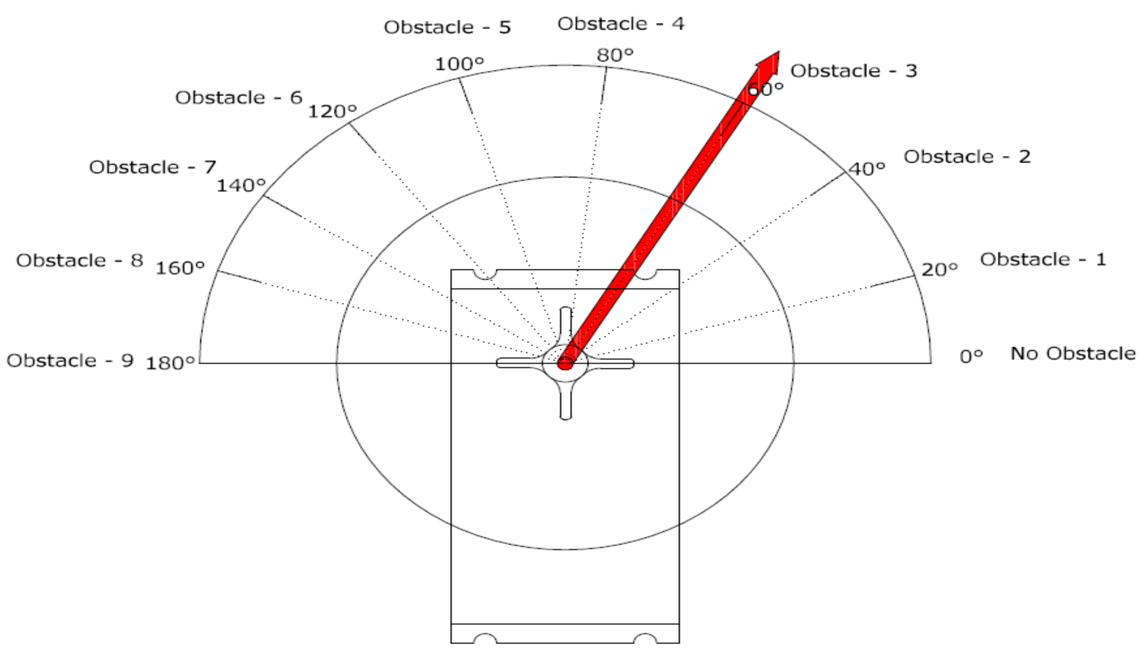


Figure 5.1 Servo positions showing types of obstacles

5.4 Strategy for Control of the Smart Walking Support System for the Blind

This device is only used when the user intends to walk or move from one place to another. Therefore, a switch either to turn ON or OFF for the device will be available and located at the side of the user where it is easy to reach. Once the user turns the switch ON, the smart walking support system will be active and the ultrasonic sensor will start to scan the environment.

When the ultrasonic sensor is active, it will emit a short burst of ultrasonic wave when it is “fired”. If an object is located in front of the sensor, some of the ultrasonic waves will be reflected back to the sensor, which switches into a microphone mode immediately after firing. Once the echo from the object is received by the sensor, it is be converted to electrical signal and then sends the electrical signal to the controller that controls the output of the system (figure 4.7). The controller measures the time that has elapsed between firing the ultrasound and receiving the echo. Because the velocity of ultrasound traveling through air is almost constant, the controller can easily compute the distance between the object and the sensor from the measured time-of-flight. The ultrasonic sensors used here have a maximum range of 3.3 meters.

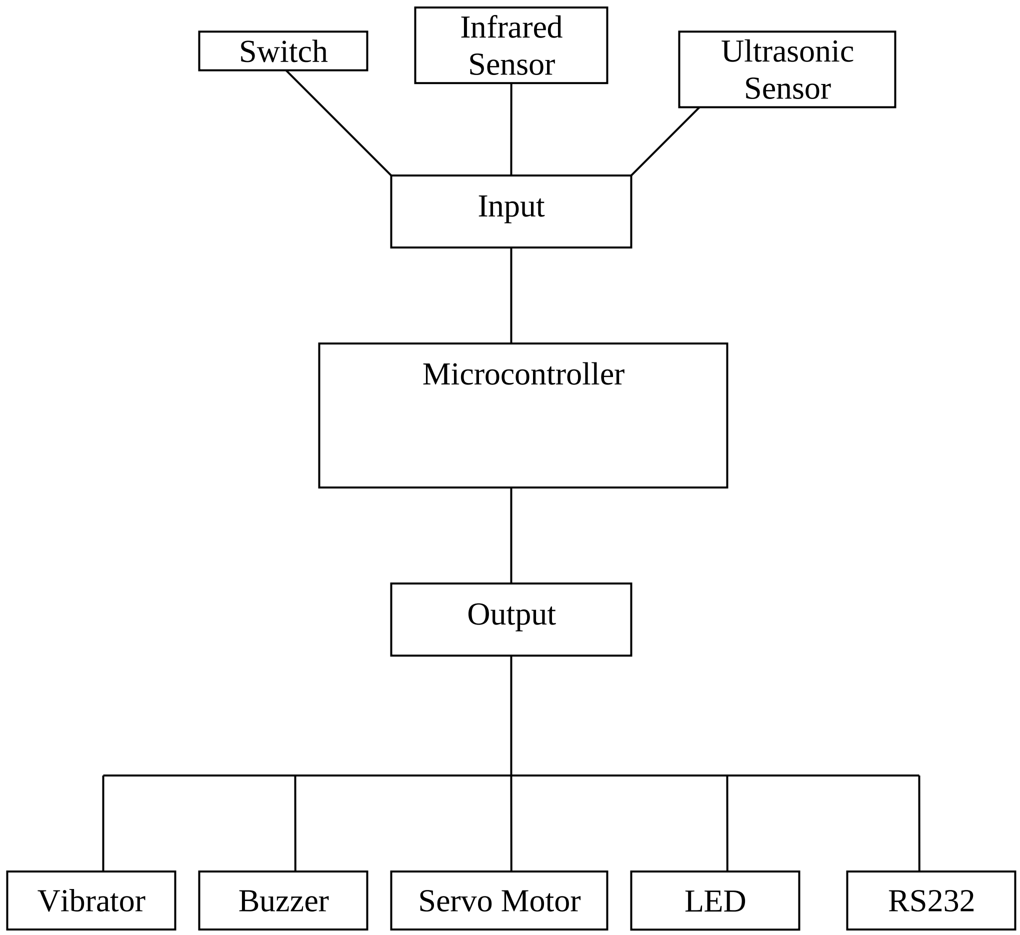


Figure 5.2 Block diagram representing the basic control system

Ultrasound waves propagate from the sensor in a cone-shaped propagation profile, in which the opening angle of the cone is about 40^0. This arrangement for each of the ultrasonic sensors assures coverage of the area in front of the user. One major difficulty in the use of multiple ultrasonic sensors is the fact that these sensors can cause mutual interference, called crosstalk. Crosstalk is a phenomenon in which the wave-front emitted by one of the ultrasonic sensor secularly reflects off smooth surfaces and is subsequently detected by another ultrasonic sensor. In the past, researchers had to employ slow firing schemes to allow each sensor's signal to dissipate before the next sensor was fired.

Therefore, this problem is avoided by making sure that the ultrasound fired by each sensor does not interfere with each other. This problem is solved by taking into consideration the maximum distance for the neighboring sensor. The case for ultrasound wave overlapping with the neighboring sensor will not occur for this setup.

For the walking support system for the blind named as belt for blind, it will start off by simply scanning the area of interest that is about 120^0 in front of the user and only 40 degree at the back of the user as shown in the flowchart (figure 5.5). Once it detects an object, it will determine whether the object is constantly exists or not and are shown in the flowchart as in figure 5.6. For example, the hand movement will cause a disturbance to the sensor because it will detect the hand as an object once the hand swings in front of the sensor. This problem is resolved by making a counter in order to determine the object really exist in front of the sensor. The counter will count for 3 milliseconds and after that, it will verify that the object exists in front of the sensor.

After the verification of an obstacle whether it is on the front, right, or left it will classify the obstacle as stair, hole, drop off and so on. The problem will arise when the user is walking fast. This will make the vibrator for the respective direction to vibrate and thus making the user to slow down the movement in order to make sure that he can follow the guidance from the vibrator to a safe path. Hence, a user will be able to follow the direction safely only if he walks slowly. This occurs because of the step distance when the user walks. Normally, for our case, the user has a step distance of 0.4 meter. Therefore, from the analysis, the sensor will suddenly move 0.4 meter in front. But for a mobile robot, the robot moves forward step by step and therefore it can move fast because the step distance can be less than 5cm. due to the step distance, the sensor needs to have a fast response in order to send the signal to the microcontroller to the output system.

Once the obstacle has been overcome, the entire servo position and buzzer will be turned off and the controller will loop back to scanning the area of interest. The block diagram in figure 5.2 shows the basic control system.

In brief, the belt is consisting of five sensors placed in different position and orientation so that we can cover a satisfactory safety distance for the user to navigate his way. Sensor S1and S2 are placed downward to detect mainly stair and hole. Sensor S3 and S4 are placed in front of the belt to find any obstacles in front of it and all these four are ultrasonic sensors. Lastly, there is another sensor named sharp infrared sensor which is located at the top of the belt for detecting overhead obstacles. There is a micro controller to get data from environment. LCD, buzzer and a servo motor have used to actuating the sensing signal.

5.5 Flow chart on strategy of walking support system for the blind

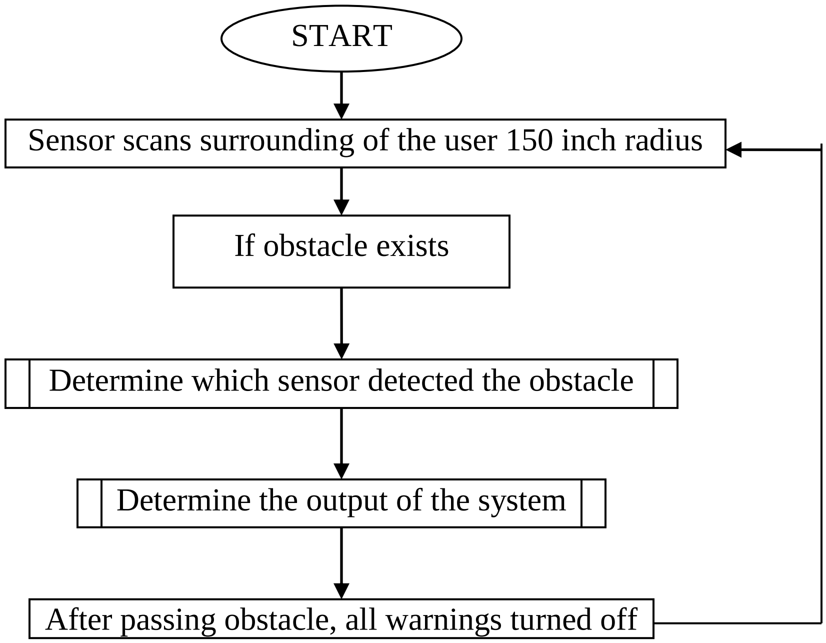


Figure 5.3 main flowcharts for Walking Support System

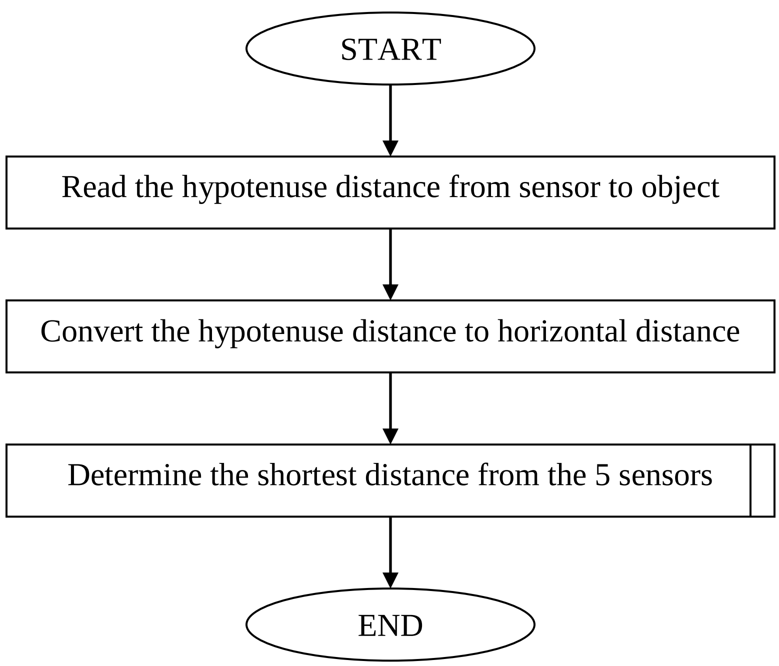
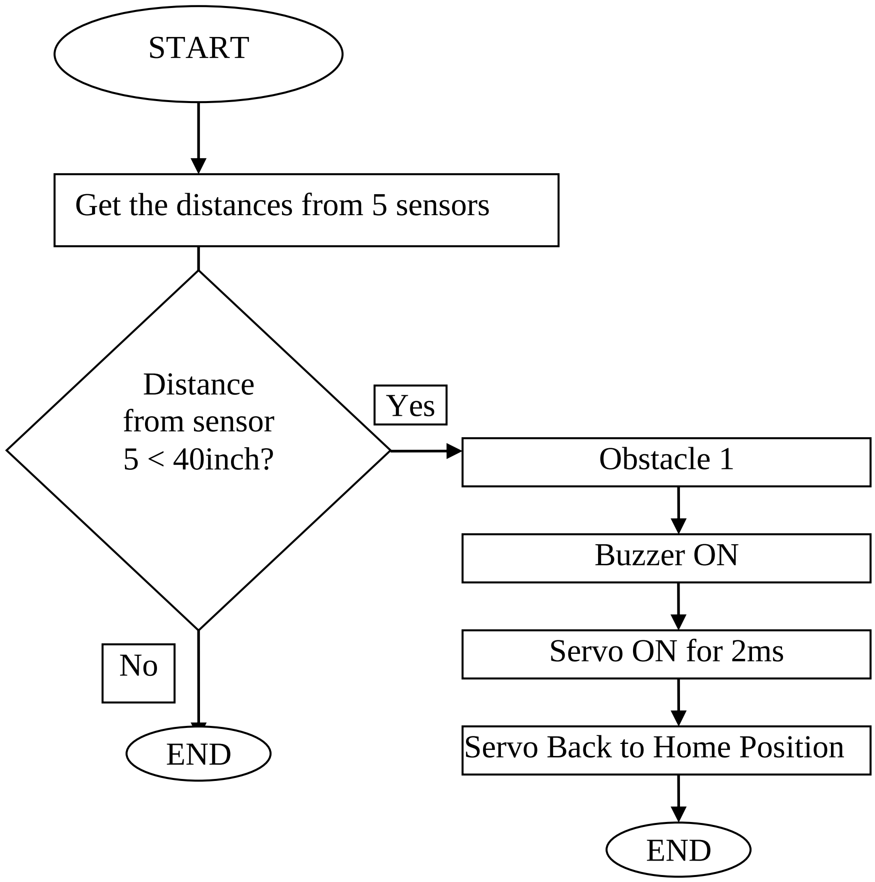
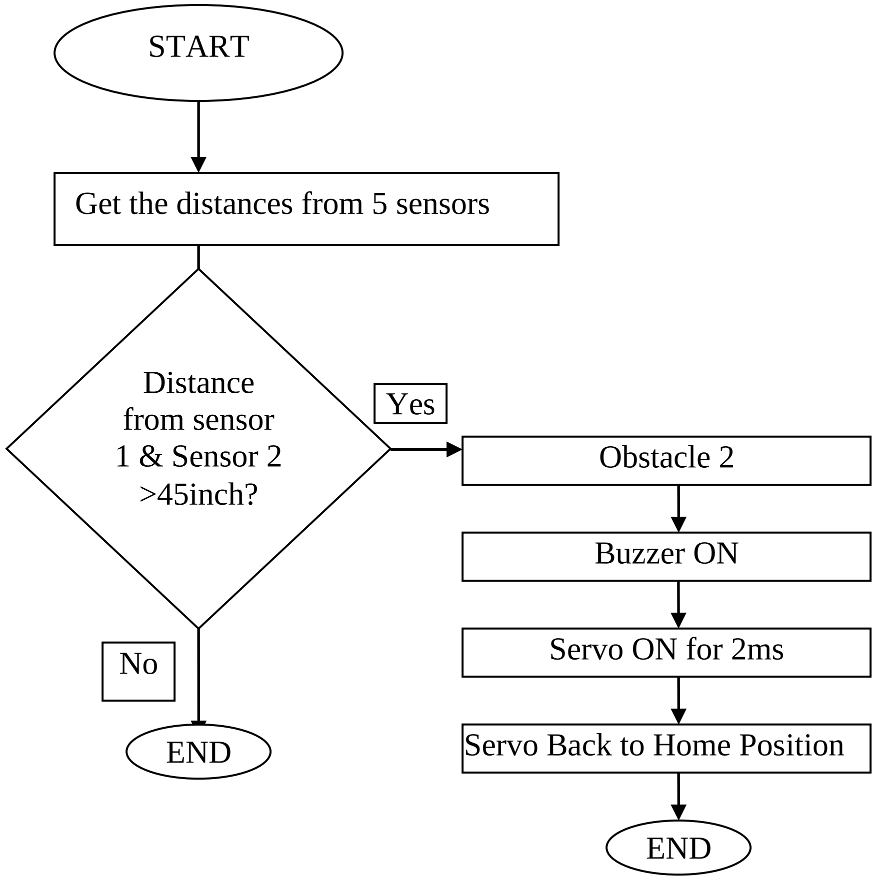


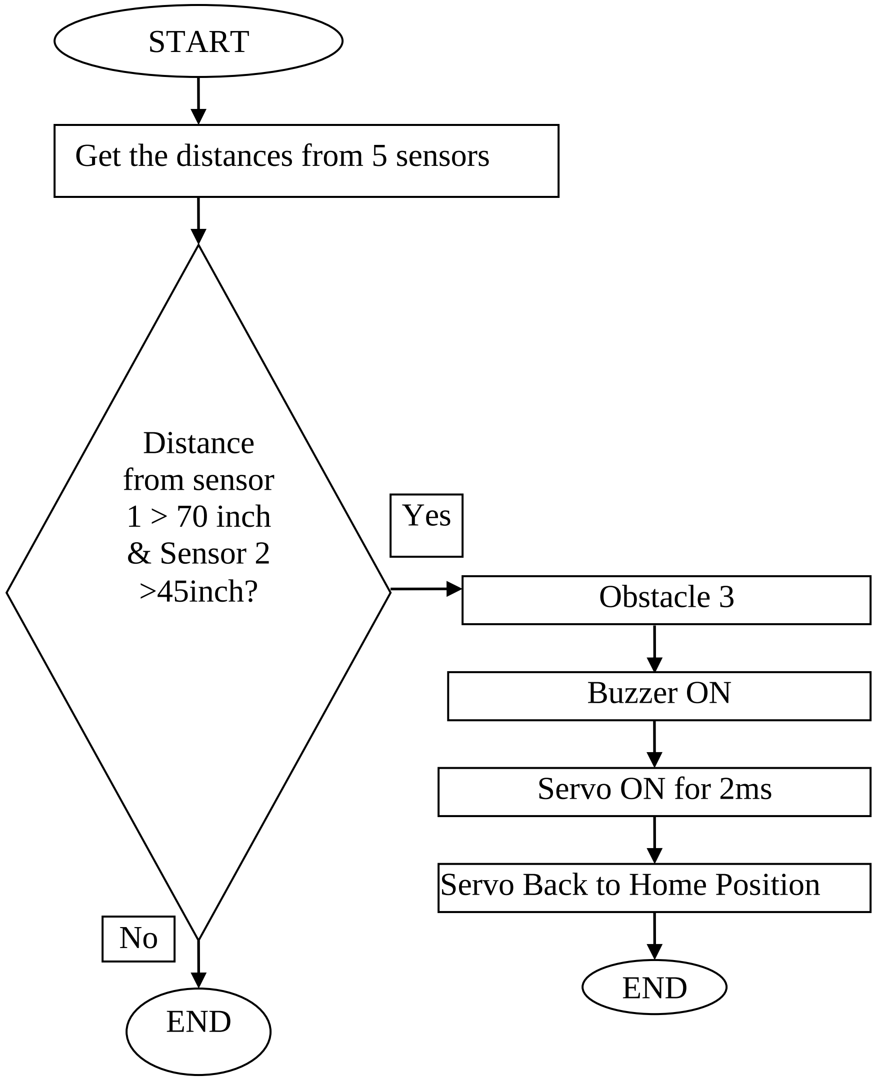
Figure 5.4 Flowchart determining which sensor detected the obstacle



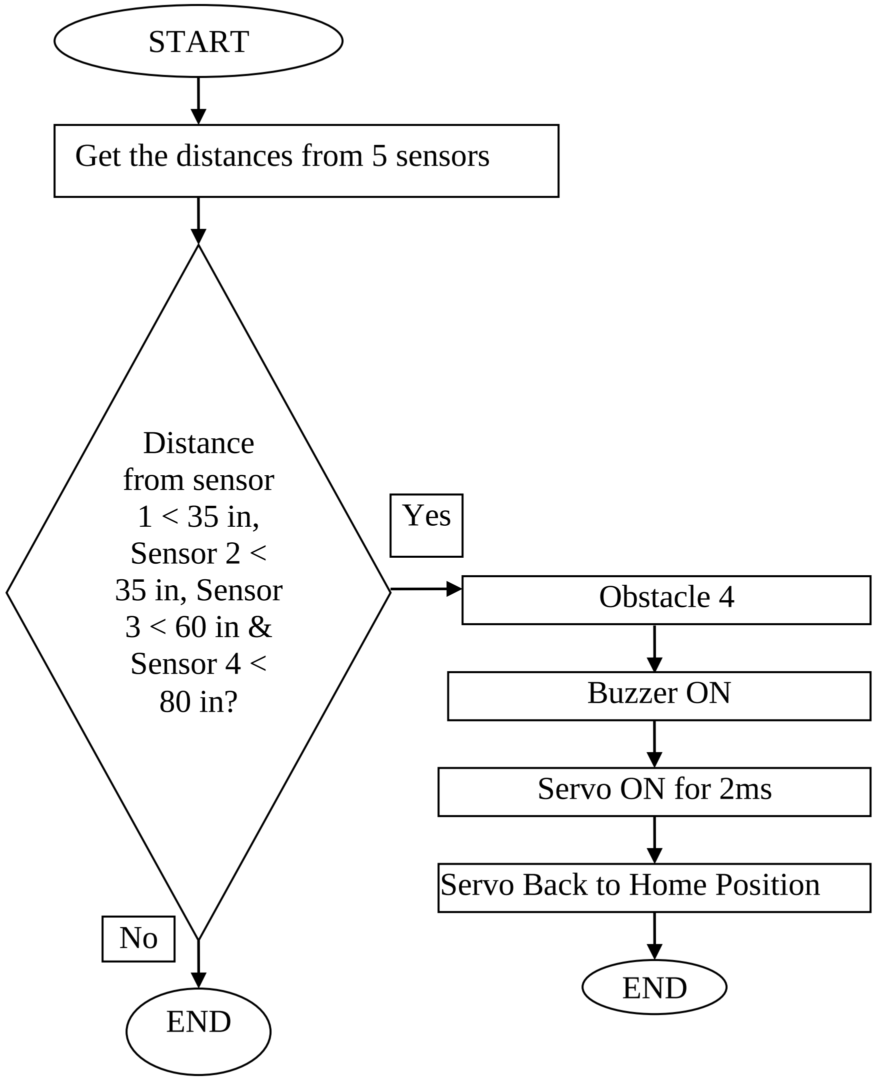
(a) Over Head obstacle



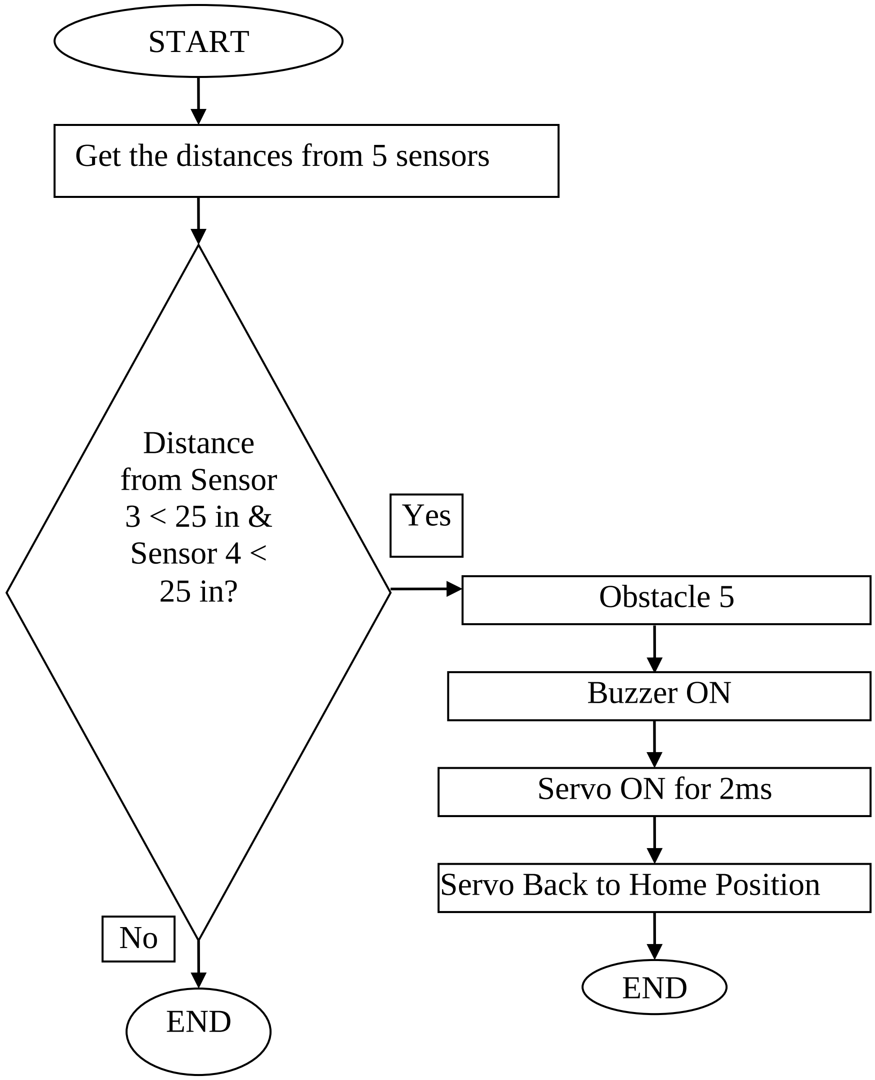
(b) Stair down obstacle



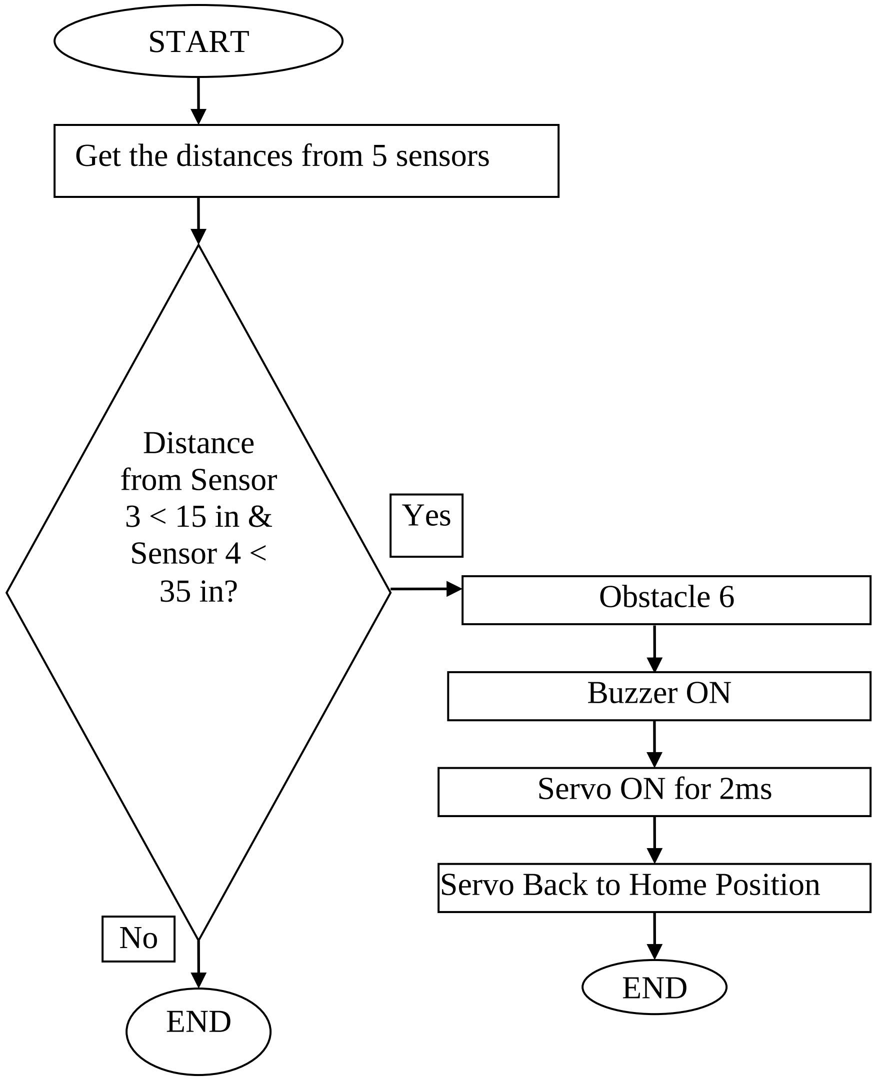
(c) Hole obstacle



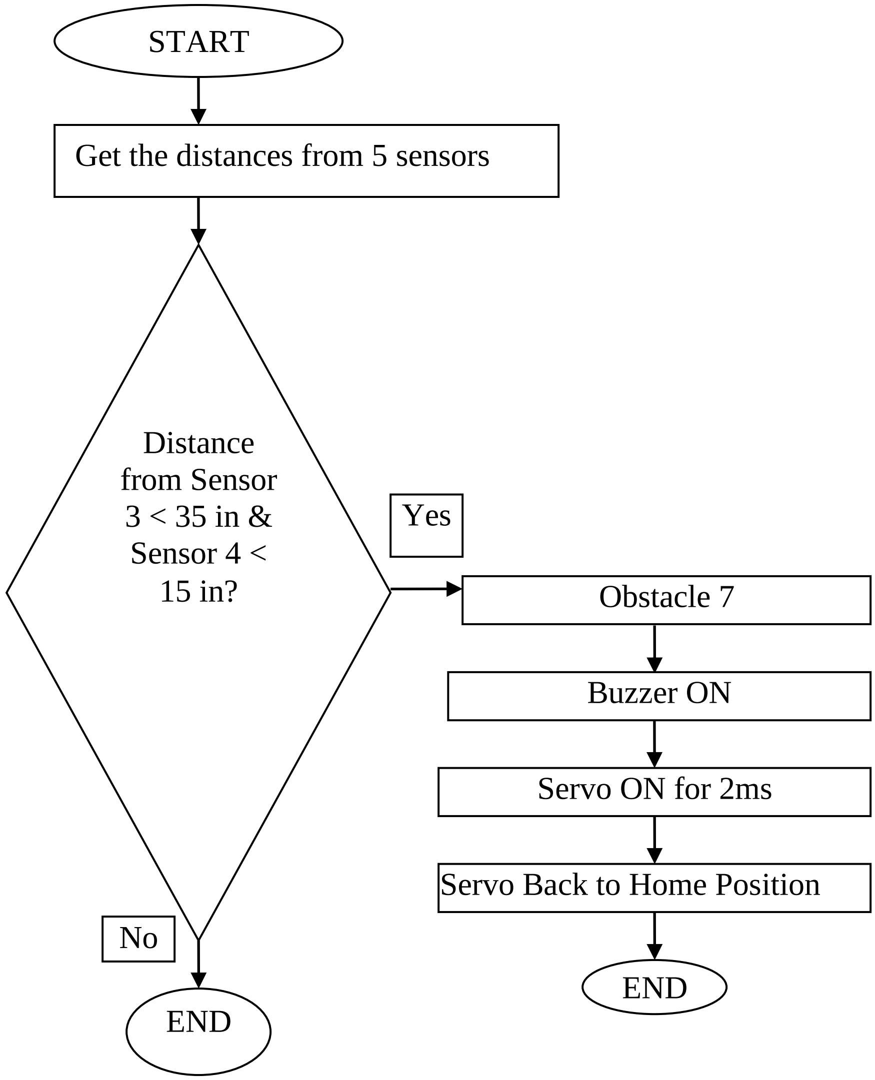
(d) Stair up obstacle



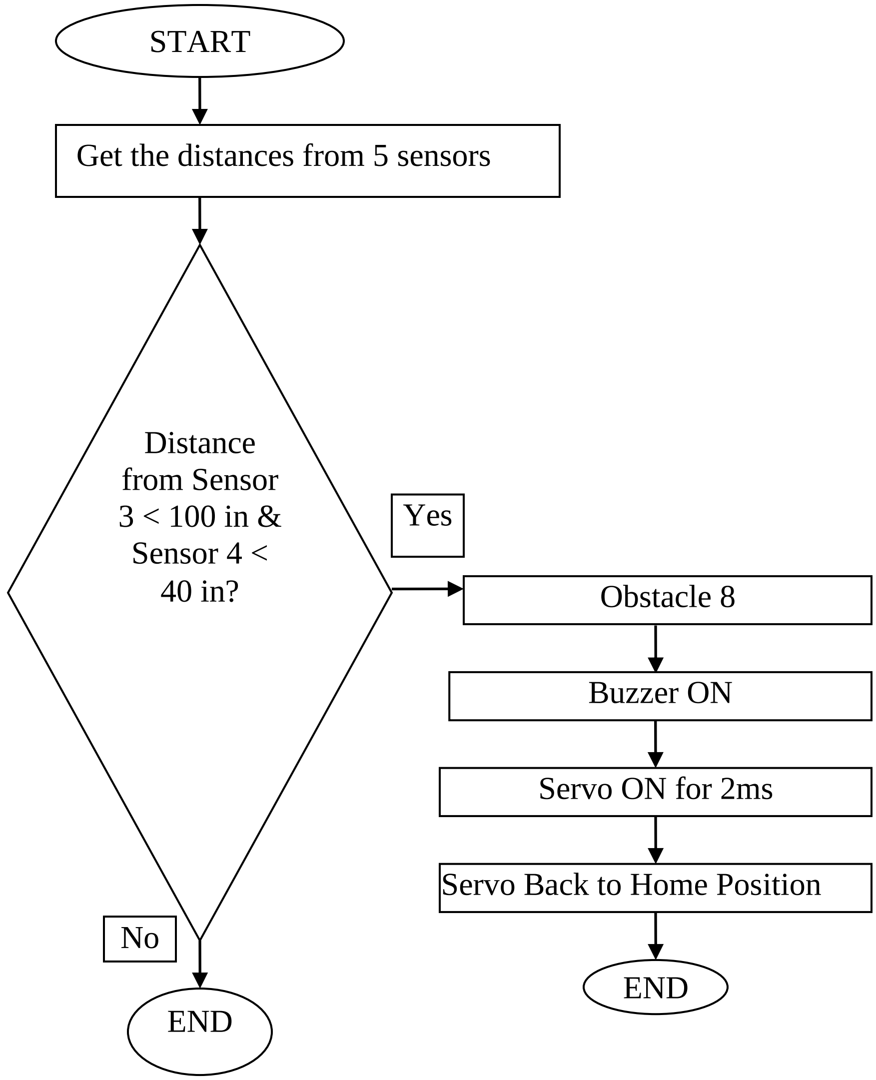
(e) Wall obstacle



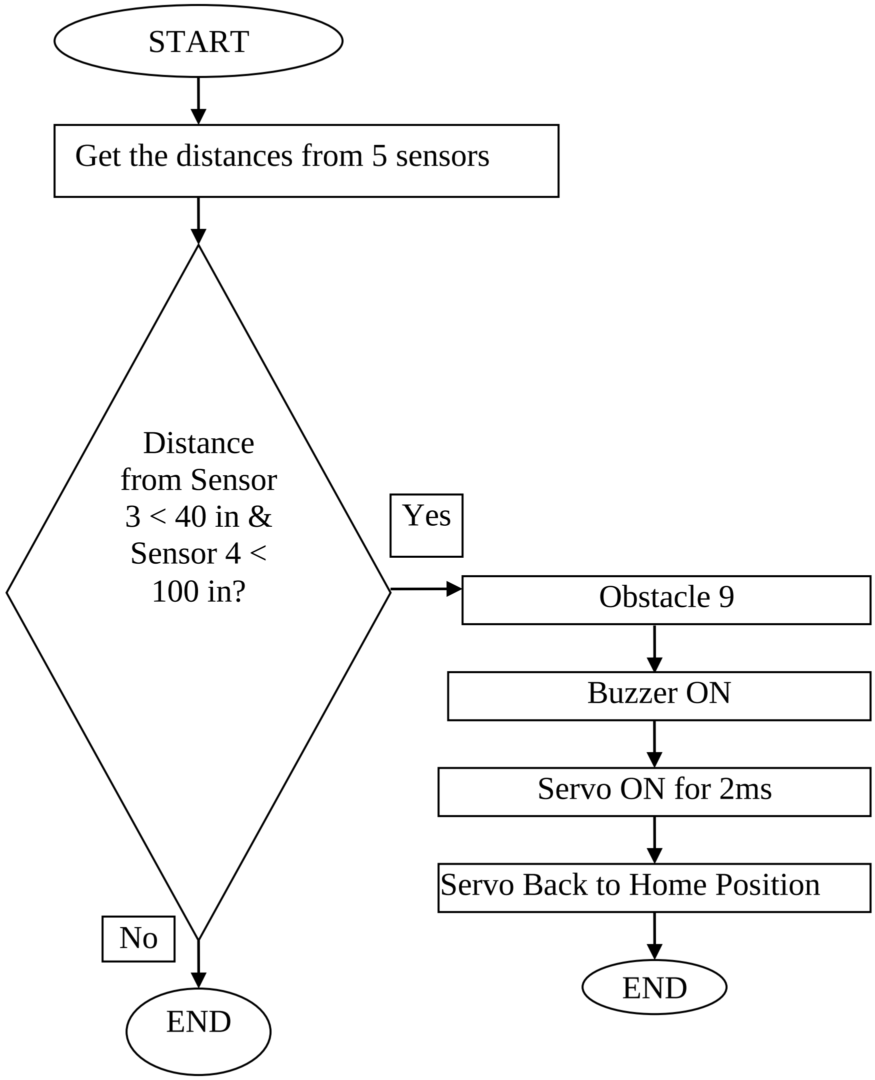
(f) Front left obstacle



(g) Front right obstacle



(h) Drop Off left obstacle



(i) Drop Off right obstacle

Figure 5.5 (a) to (i) Flowchart for detecting various obstacles in front of the user

5.6 Algorithm for the walking support system

"Switch ON"

Begin

Initialized: S1, S2, S3, S4, S5 $\in$ {0}

S $\in$ {0º position with no obstacle}

Repeat

Begin

If S5 < 50 then Obs1

Begin

B and S $\in$ {20º position for 02 sec}

S $\in$ {0º position}

End;

If 45 < S1 < 52 *and* 45 < S2 < 52 then Obs2

Begin

B and S $\in$ {40º position for 02 sec}

S $\in$ {0º position}

End;

If S1 > 55 *and* S2 > 55 then Obs3

Begin

B and S $\in$ {60º position for 02 sec}

S $\in$ {0º position}

End;

If S1 < 35 *and* S2 < 35 *and* S3 < 60 *and* S4 < 60 then Obs4

Begin

B and S $\in$ {80º position for 02 sec}

S $\in$ {0º position}

End;

If S3 < 25 *and* S4 < 25 then Obs5

Begin

B and S $\in$ {100º position for 02 sec}

S $\in$ {0º position}

End;

If S3 < 15 *and* S4 < 35 then Obs6

Begin

B and S $\in$ {120º position for 02 sec}

S $\in$ {0º position}

End;

If S3 < 35 *and* S4 < 15 then Obs7

Begin

B and S $\in$ {140º position for 02 sec}

S $\in$ {0º position}

End;

If S3 > 55 *and* S4 < 40 then Obs8

Begin

B and S $\in$ {160º position for 02 sec}

```
            S ∈ {0º position}
        End;
    If S3 < 40 and S4 > 55 then Obs9
        Begin
            B and S ∈ {180º position for 02 sec}
            S ∈ {0º position}
        End;
  End;
 Until "Switch OFF"
End.
```

5.7 *Obstacle Avoidance*

In this experiment, we are testing the efficiency of the system using obstacle placed randomly in front of the user. A volunteer is chosen randomly, a brief explanation was given on how to follow instructions from the smart walking support system. When the volunteer understands on how the system works, he is taken blindfolded. Obstacle was placed randomly in front of him and he is instructed to move forward with the guidance of the walking support system. The setup is shown in Figure 5.6**:**

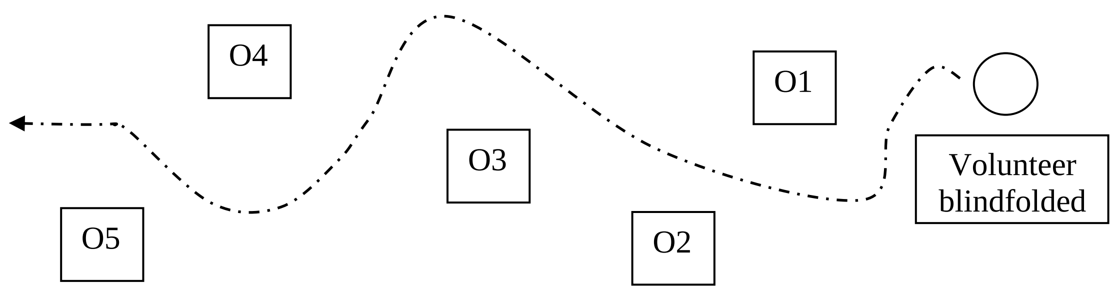


Figure 5.6 Setup of obstacle avoidance experiment

The experiment is done with 3 volunteers and the results are satisfactory. A blindfolded user walks slowly due to the fear of collision with the obstacle, thus the volunteer has sufficient time to respond to the instructions given. The setup of the obstacle was changed to check for efficiency of the system. The user will walk forward, detecting O1, buzzer and servo will switch ON and the user moves to his left. He then walks forward and detects another obstacle O2 and obstacle O3, then again buzzer will turn ON and also servo will move some angle based on obstacle type and the user walks avoiding going to his left according to the servo instruction. Similarly, the last object can be avoided.

5.8 Results

Various obstacles are being detected via actuation systems. We went to Malaysian Association for Blind (MAB) for testing our prototype. They have recommended our device as a great work for blind people's navigation. Figure 5.7 (a) and (b) shows MAB personnel using the system in an unknown environment.

(a) Wall Detection (b) Hole Detection

Figure 5.7 MAB personnel testing Belt for Blind

5.9 Summary

In this chapter algorithm for detecting various obstacles is developed. Sensors, actuators and software are integrated to convey mapping of the surrounding for smooth movement of visually impaired person. Experiments conducted both with blind folded person and by birth blind person are conducted successfully to validate the functionality of the prototype of the Walking Support System designed and developed in this research.

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1 CONTRIBUTION OF THE STUDY

The Belt for Blind system developed through this research aids visually impaired peoples navigate smoother, both indoor and outdoor. A new Walking Support System for the visually impaired people, as per the definition of visually impaired provided earlier where the term blindness refers to people who have no sight at all as well as to those considered as blind have limited vision, was proposed, and the objectives of designing this walking aids for blind are fulfilled. The purpose of this study was to examine through Mathematical model whether we will get sufficient data using ultrasonic sensor for getting stair and hole or not, and this was successfully achieved at the stages of experimentation setup, terrain detection, performance analysis, and real-time implementation. Contribution made in this undertaking is listed below:

- Mathematical Model for Optimizing sensor orientation and walking pace for getting adequate data
- Stair Detection (Classified it as a stair up and stair down)
- Hole and Drop off detection
- GUI development for acquiring data
- Design and fabrication of prototype,
- Development of algorithm for detecting obstacles

- A servo motor and a buzzer integrated to the system to that help the user understand the type of obstacles ahead.

6.2 CONCLUSION

The following conclusions are made based on the outcomes of this research:

1. A Mathematical Model is developed that helped in deciding proper orientation of sensors and walking pace of a visually impaired user for detecting critical obstacles like stair down, hole, and drop offs.
2. Algorithms are developed through extensive experimentations that are able to differentiate different obstacles around the walkway of a blind person.
3. A new Walking Support System for the visually impaired people named as 'Belt for Blind' is developed for detecting information about terrain where the environment consists of various obstacles such as stair, hole and so on.
4. The walking support system is incorporated with actuation system that is able to convey interpretation of obstacles around the user successfully.
5. The prototype of the system is successfully tested on a blind user with minimum training.

The system passed the ultimate test of real-time implementation on a prototype. In addition to fulfilling the objectives, certain characteristics about the structure were also ascertained

1. As expected, the device is equipped with a servo motor and a buzzer to generate outputs that inform the user about the type of the obstacle ahead

2. The configurations calculated at the Modeling and experimental stages were validated through the performance of the prototype.
3. The successful execution of the sensing signal also affirmed the suitability of the control algorithm.

6.3 RECOMMENDATIONS

Though the objectives are fulfilled, certain limitations are clearly observed in the study.

1. This prototype cannot differentiate between animate and inanimate obstacles. So in further works it should consider this issue.
2. This device is limited to standard pace of mobility of the user. It requires making more sophisticated system so that user can walk at a pace of a normal human.
3. The used sensors sometimes are affected with temperature and humidity and also its accuracy and precision is not enough to get proper data. It is my recommendation that use more filter to eliminate all possible noise from the system.
4. For complete walking support system, one should plan for more sensors to further enhance mapping capability of the system. In such case it is expected number obstacle scenario will increase significantly, which would need alpha numeric brail representations.
5. To train scenario information better, Neuron Network could be applied.

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APPENDIX I: Interview information of Malaysian Blind Association for Blind (MAB)

Mon, June 22, 2009 11:53:55 AM
From: Silatul Rahim Bin Dahman
<rahim@mab.org.my>
...
Add to Contacts
To: eklashossain@yahoo.com

Greetings from MAB.

Here are some info which could help you in your research:
q: 1. how do the blind decide there is a object in front of him by using only sticks and which type of action they usually take about those obstacles
a: The stick is one of the many tools used by the blind persons to detect obstacles around them while moving from Point A to Point B. When the stick touches an object such as trees, lamp posts, cars, flower pots, dustbeen, drains etc, the blind would take appropriate actions such as move away from those obstacles, find their way around those objects and just continue moving safely. The stick could also detect different surface of the ground or floor such as smooth or rough surface, slopy or hilly ground, steps, wide or narrow space etc.
Besides stick, there are so many other tools used by the blind to move around such as guide dog, human guide, talking GPS, hearing sense, smelling sense and use their foot and hands to feel the surrounding.

q: 2. How they make the difference among varies objects, those obstacle is .make by wood/metal/man/water.
a: Different objects would produce different sounds such as metal objects produce a high pitch sound when the stick hit it, wood produces low pitch sound, water surely produces water sound etc. Soft objects such as grass, carpet, cloth, rubber and cotton produce soft sound or no sound at all. However, the blind don't really need to know what object or obstacle in front of them as long as they are safe to go through those obstacles, but they need to know all objects that are available in their home or office so that they can find their things easily and independently.

q: 3. How do you decide about steps/ Stair/ hole/drain and its size and deep. means how you understand the obstacle would be over come or you have to change the way.
a: as described in q 1.
q: 4. Which type of actuation system do you like most..is sound or vibration or bell or symbol. and which will be better place put those things in hand or neck or any others place.
a: combination of all senses would be a perfect system.

Regards,
Rahim

APPENDIX II: Development of GUI Using VB++

```
Private Sub Form_Load()
' Fire Rx Event Every Two Bytes
MSComm1.RThreshold = 8

' When Inputting Data, Input 2 Bytes at a time
MSComm1.InputLen = 8

' 2400 Baud, No Parity, 8 Data Bits, 1 Stop Bit
MSComm1.Settings = "9600,N,8,1"
' Disable DTR
MSComm1.DTREnable = False

' Open COM1
MSComm1.CommPort = 8
MSComm1.PortOpen = True

End Sub

Private Sub MSComm1_OnComm()
Dim s As String
Dim A1 As String
Dim A2 As String
Dim A3 As String
Dim A4 As String
Dim A5 As String
Dim A6 As String

If MSComm1.CommEvent = comEvReceive Then

 s = MSComm1.Input ' Get data (2 bytes)

 'Debug.Print s
A1 = Mid(s, 2, 1)
Debug.Print A1
If A1 = "A" Then
Text1.Text = Mid(s, 4, 4)
List1.AddItem Date & Time & Space(1) & "Sensor1" & Space(1) & Text1.Text
Open App.Path & "\data.log" For Append As #1
Print #1, Date & " " & Time & " " & "Sensor1" & Space(1) & Text1.Text
Close #1
ElseIf A1 = "B" Then
Text2.Text = Mid(s, 4, 4)
List1.AddItem Date & Time & Space(1) & "Sensor2" & Space(1) & Text2.Text
```

```
Open App.Path & "\data.log" For Append As #1
Print #1, Date & " " & Time & " " & "Sensor2" & Space(1) & Text2.Text
Close #1
ElseIf A1 = "C" Then
Text3.Text = Mid(s, 4, 4)
List1.AddItem Date & Time & Space(1) & "Sensor3" & Space(1) & Text3.Text
Open App.Path & "\data.log" For Append As #1
Print #1, Date & " " & Time & " " & "Sensor3" & Space(1) & Text3.Text
Close #1
ElseIf A1 = "D" Then
Text4.Text = Mid(s, 4, 4)
List1.AddItem Date & Time & Space(1) & "Sensor4" & Space(1) & Text4.Text
Open App.Path & "\data.log" For Append As #1
Print #1, Date & " " & Time & " " & "Sensor4" & Space(1) & Text4.Text
Close #1
ElseIf A1 = "E" Then
Text5.Text = Mid(s, 4, 4)
List1.AddItem Date & Time & Space(1) & "Sensor5" & Space(1) & Text5.Text
Open App.Path & "\data.log" For Append As #1
Print #1, Date & " " & Time & " " & "Sensor5" & Space(1) & Text5.Text
Close #1
ElseIf A1 = "F" Then
Text6.Text = Mid(s, 4, 4)
List1.AddItem Date & Time & Space(1) & "Sensor6" & Space(1) & Text6.Text
Open App.Path & "\data.log" For Append As #1
Print #1, Date & " " & Time & " " & "Sensor6" & Space(1) & Text6.Text
Close #1
End If
'Debug.Print A1
'Debug.Print A2
'Debug.Print A3


End If

End Sub

Private Sub Label1_Click()

End Sub

Private Sub Label2_Click()

End Sub

Private Sub Label3_Click()
```

```
End Sub

Private Sub Label4_Click()

End Sub

Private Sub Label5_Click()

End Sub

Private Sub Label6_Click()

End Sub

Private Sub Label7_Click()

End Sub

Private Sub Label8_Click()

End Sub

Private Sub List1_Click()

End Sub

Private Sub MSComm1_Click()

End Sub

Private Sub showGraph_Click()
Graph.Show
End Sub

Private Sub Text1_Change()

End Sub

Private Sub Text2_Change()

End Sub

Private Sub Text3_Change()

End Sub
```

```
Private Sub Text4_Change()

End Sub

Private Sub Text5_Change()

End Sub

Private Sub Text6_Change()

End Sub

Private Sub Timer1_Timer()
Label8.Caption = Date & Space(2) & Time
End Sub
```

APPENDIX III: Program for terrain Detection

```
#define buzzer PORTC.F3
#define led PORTC.F2

char txt[6];
char j;
double range;
double range1;
double range2;
double range3;
double range4;
double range5;

unsigned double ir1;

int total_range;
int temp_range;

double read_range(char);
double read_ir(char);
void beep(void);

void main()
{
 ADCON1 = 0x80;            // Configure analog inputs and Vref
 TRISA  = 0b11111111;           // PORTA is input
 TRISB  = 0x00;            //
 TRISC  = 0b00000000;
 TRISD  = 0b11111111;
 TRISE  = 0b00000111;
 INTCON = 0xA0;
 OPTION_REG = 0b10000110;
 LCD_Config(&PORTB,4,5,6,3,2,1,0);
 Lcd_Init(&PORTB);                    // Lcd_Init_EP4, see Autocomplete
 LCD_Cmd(LCD_CURSOR_OFF);              // send command to LCD (cursor off)
 LCD_Cmd(LCD_CLEAR);                  // send command  to LCD (clear LCD)
 LCD_Cmd(LCD_CLEAR);
 led=1;


 do
 {
  range1=read_range(0);
  for(j=0;j<=6;j++)
```

```
txt[j]=0;
Lcd_out(1,1,"A:");
floatToStr(range1, txt);
Lcd_chr_cp(txt[0]);
Lcd_chr_cp(txt[1]);
Lcd_chr_cp(txt[2]);
Lcd_chr_cp(txt[3]);
if(range1<=10)
{
 beep();
}
//  Lcd_chr_cp(txt[4]);

range2=read_range(1);
for(j=0;j<=6;j++)
txt[j]=0;
Lcd_out(1,8,"B:");
floatToStr(range2, txt);
Lcd_chr_cp(txt[0]);
Lcd_chr_cp(txt[1]);
Lcd_chr_cp(txt[2]);
Lcd_chr_cp(txt[3]);
if(range2<=10)
{
 beep();
}
//  Lcd_chr_cp(txt[4]);

range3=read_range(2);
for(j=0;j<=6;j++)
txt[j]=0;
Lcd_out(1,15,"C:");
floatToStr(range3, txt);
Lcd_chr_cp(txt[0]);
Lcd_chr_cp(txt[1]);
Lcd_chr_cp(txt[2]);
Lcd_chr_cp(txt[3]);
if(range3<=10)
{
 beep();
}
//  Lcd_chr_cp(txt[4]);

range4=read_range(3);
for(j=0;j<=6;j++)
txt[j]=0;
```

```
  Lcd_out(2,1,"D:");
  floatToStr(range4, txt);
  Lcd_chr_cp(txt[0]);
  Lcd_chr_cp(txt[1]);
  Lcd_chr_cp(txt[2]);
  Lcd_chr_cp(txt[3]);
  if(range4<=10)
  {
   beep();
  }
//   Lcd_chr_cp(txt[4]);

  range5=read_range(6);
  for(j=0;j<=6;j++)
  txt[j]=0;
  Lcd_out(2,8,"E:");
  floatToStr(range5, txt);
  Lcd_chr_cp(txt[0]);
  Lcd_chr_cp(txt[1]);
  Lcd_chr_cp(txt[2]);
  Lcd_chr_cp(txt[3]);
  if(range5<=10)
  {
   beep();
  }
//   Lcd_chr_cp(txt[4]);

  ir1=read_ir(4);
  ir1=(3.3-ir1)/0.03;
  for(j=0;j<=6;j++)
  txt[j]=0;
  Lcd_out(2,15,"F:");
  floatToStr(ir1, txt);
  Lcd_chr_cp(txt[0]);
  Lcd_chr_cp(txt[1]);
  Lcd_chr_cp(txt[2]);
  Lcd_chr_cp(txt[3]);
  if(ir1<=10)
  {
   beep();
  }
//   Lcd_chr_cp(txt[4]);

  Delay_ms(100);

 }while(1);
```

```
}

//*********************************************************************
*******

double read_range(char x)
{
   total_range =0;
   for (j=0; j<=20; j++){
   temp_range = ADC_Read(x);
   total_range =total_range + temp_range ;
   }
   range = (total_range/20);
   range = ((range * 5)/1023)* 100 ;
   return range;
}

double read_ir(char x)
{
   total_range =0;
   for (j=0; j<=20; j++){
   temp_range = ADC_Read(x);
   total_range =total_range + temp_range ;
   }
   range = (total_range/20);
   range = ((range * 5)/1023) ;
   return range;
}

//*********************************************************************
******

void beep(void)
{
 buzzer=1;
 delay_ms(100);
 buzzer=0;
 delay_ms(100);
}
```

APPENDIX IV: Program for Actuation

```
#define buzzer PORTC.F3
#define led PORTC.F2

char txt[6];
char j;
double range;
double range1;
double range2;
double range3;
double range4;
double range5;

unsigned double ir1;

int total_range;
int temp_range;

double read_range(char);
double read_ir(char);
void beep(void);

void main()
{
 ADCON1 = 0x80;            // Configure analog inputs and Vref
 TRISA  = 0b11111111;           // PORTA is input
 TRISB  = 0x00;            //
 TRISC  = 0b10000000;
 TRISD  = 0b11111111;
 TRISE  = 0b00000111;
 OPTION_REG = 0b10000110;
 LCD_Config(&PORTB,4,5,6,3,2,1,0);
 Lcd_Init(&PORTB);                  // Lcd_Init_EP4, see Autocomplete
 LCD_Cmd(LCD_CURSOR_OFF);              // send command to LCD (cursor off)
 LCD_Cmd(LCD_CLEAR);                  // send command  to LCD (clear LCD)
 Usart_init(9600);
//  Lcd_Out(1,1, " Smart AirCon");
//  Lcd_Out(2,1, "  Control Sys  ");
//  Delay_ms(2000);
 LCD_Cmd(LCD_CLEAR);
 led=1;


 do
```

```
 {
  range1=read_range(0);
  for(j=0;j<=6;j++)
  txt[j]=0;
  Lcd_out(1,1,"A:");
  floatToStr(range1, txt);
  Lcd_chr_cp(txt[0]);
  Lcd_chr_cp(txt[1]);
  Lcd_chr_cp(txt[2]);
  Lcd_chr_cp(txt[3]);
  usart_write('[');
  usart_write('A');
  usart_write(':');
  usart_write(txt[0]);
  usart_write(txt[1]);
  usart_write(txt[2]);
  usart_write(txt[3]);
  usart_write(']');
  if(range1<=10)
  {
   beep();
  }
//   Lcd_chr_cp(txt[4]);

  range2=read_range(1);
  for(j=0;j<=6;j++)
  txt[j]=0;
  Lcd_out(1,8,"B:");
  floatToStr(range2, txt);
  Lcd_chr_cp(txt[0]);
  Lcd_chr_cp(txt[1]);
  Lcd_chr_cp(txt[2]);
  Lcd_chr_cp(txt[3]);
  usart_write('[');
  usart_write('B');
  usart_write(':');
  usart_write(txt[0]);
  usart_write(txt[1]);
  usart_write(txt[2]);
  usart_write(txt[3]);
  usart_write(']');
  if(range2<=10)
  {
   beep();
  }
//   Lcd_chr_cp(txt[4]);
```

```
   range3=read_range(2);
   for(j=0;j<=6;j++)
   txt[j]=0;
   Lcd_out(1,15,"C:");
   floatToStr(range3, txt);
   Lcd_chr_cp(txt[0]);
   Lcd_chr_cp(txt[1]);
   Lcd_chr_cp(txt[2]);
   Lcd_chr_cp(txt[3]);
   usart_write('[');
   usart_write('C');
   usart_write(':');
   usart_write(txt[0]);
   usart_write(txt[1]);
   usart_write(txt[2]);
   usart_write(txt[3]);
   usart_write(']');
   if(range3<=10)
   {
    beep();
   }
//   Lcd_chr_cp(txt[4]);

   range4=read_range(3);
   for(j=0;j<=6;j++)
   txt[j]=0;
   Lcd_out(2,1,"D:");
   floatToStr(range4, txt);
   Lcd_chr_cp(txt[0]);
   Lcd_chr_cp(txt[1]);
   Lcd_chr_cp(txt[2]);
   Lcd_chr_cp(txt[3]);
   usart_write('[');
   usart_write('D');
   usart_write(':');
   usart_write(txt[0]);
   usart_write(txt[1]);
   usart_write(txt[2]);
   usart_write(txt[3]);
   usart_write(']');
   if(range4<=10)
   {
    beep();
   }
//   Lcd_chr_cp(txt[4]);
```

```
range5=read_range(6);
for(j=0;j<=6;j++)
txt[j]=0;
Lcd_out(2,8,"E:");
floatToStr(range5, txt);
Lcd_chr_cp(txt[0]);
Lcd_chr_cp(txt[1]);
Lcd_chr_cp(txt[2]);
Lcd_chr_cp(txt[3]);
usart_write('[');
usart_write('E');
usart_write(':');
usart_write(txt[0]);
usart_write(txt[1]);
usart_write(txt[2]);
usart_write(txt[3]);
usart_write(']');
if(range5<=10)
{
 beep();
}
//   Lcd_chr_cp(txt[4]);

ir1=read_ir(4);
ir1=(3.3-ir1)/0.03;
for(j=0;j<=6;j++)
txt[j]=0;
Lcd_out(2,15,"F:");
floatToStr(ir1, txt);
Lcd_chr_cp(txt[0]);
Lcd_chr_cp(txt[1]);
Lcd_chr_cp(txt[2]);
Lcd_chr_cp(txt[3]);
usart_write('[');
usart_write('F');
usart_write(':');
usart_write(txt[0]);
usart_write(txt[1]);
usart_write(txt[2]);
usart_write(txt[3]);
usart_write(']');
if(ir1<=10)
{
 beep();
}
```

```
//   Lcd_chr_cp(txt[4]);

//   Delay_ms(10);

  }while(1);

}

//*********************************************************************
*******

double read_range(char x)
{
   total_range =0;
   for (j=0; j<=20; j++){
   temp_range = ADC_Read(x);
   total_range =total_range + temp_range ;
   }
   range = (total_range/20);
   range = ((range * 5)/1023)* 100 ;
   return range;
}

double read_ir(char x)
{
   total_range =0;
   for (j=0; j<=20; j++){
   temp_range = ADC_Read(x);
   total_range =total_range + temp_range ;
   }
   range = (total_range/20);
   range = ((range * 5)/1023) ;
   return range;
}

//*********************************************************************
******

void beep(void)
{
 buzzer=1;
 delay_ms(5);
 buzzer=0;
 delay_ms(5);
}
```

```
void post1(void)
{
 beep();
 beep();
 beep();
 for(y=0;y<=30;y++)
 {
  servo=1;
  Delay_us(500);
  servo=0;
  Delay_ms(18);
 }
 Delay_ms(2000);
 for(y=0;y<=30;y++)
 {
  servo=1;
  Delay_us(500);
  servo=0;
  Delay_ms(18);
 }
 Delay_ms(1000);
}

void post2(void)
{
 beep();
 beep();
 beep();
 for(y=0;y<=30;y++)
 {
  servo=1;
  Delay_us(800);
  servo=0;
  Delay_ms(18);
 }
 Delay_ms(2000);
 for(y=0;y<=30;y++)
 {
  servo=1;
  Delay_us(800);
  servo=0;
  Delay_ms(18);
 }
 Delay_ms(1000);
}
```

```
void post3(void)
{
 beep();
 beep();
 beep();
 for(y=0;y<=30;y++)
 {
  servo=1;
  Delay_ms(1);
  Delay_us(100);
  servo=0;
  Delay_ms(18);
 }
 Delay_ms(2000);
 for(y=0;y<=30;y++)
 {
  servo=1;
  Delay_ms(1);
  Delay_us(100);
  servo=0;
  Delay_ms(18);
 }
 Delay_ms(1000);
}

void post4(void)
{
 beep();
 beep();
 beep();
 for(y=0;y<=30;y++)
 {
  servo=1;
  Delay_ms(1);
  Delay_us(400);
  servo=0;
  Delay_ms(18);
 }
 Delay_ms(2000);
 for(y=0;y<=30;y++)
 {
  servo=1;
  Delay_ms(1);
  Delay_us(400);
  servo=0;
  Delay_ms(18);
```

```
 }
 Delay_ms(1000);
}

void post5(void)
{
 beep();
 beep();
 beep();
 for(y=0;y<=30;y++)
 {
  servo=1;
  Delay_ms(1);
  Delay_us(700);
  servo=0;
  Delay_ms(18);
 }
 Delay_ms(2000);
 for(y=0;y<=30;y++)
 {
  servo=1;
  Delay_ms(1);
  Delay_us(700);
  servo=0;
  Delay_ms(18);
 }
 Delay_ms(1000);
}

void post6(void)
{
 beep();
 beep();
 beep();
 for(y=0;y<=30;y++)
 {
  servo=1;
  Delay_ms(2);
  servo=0;
  Delay_ms(18);
 }
 Delay_ms(2000);
 for(y=0;y<=30;y++)
 {
  servo=1;
  Delay_ms(2);
```

```
  servo=0;
  Delay_ms(18);
 }
 Delay_ms(1000);
}

void post7(void)
{
 beep();
 beep();
 beep();
 for(y=0;y<=30;y++)
 {
  servo=1;
  Delay_ms(2);
  Delay_us(400);
  servo=0;
  Delay_ms(18);
 }
 Delay_ms(2000);
 for(y=0;y<=30;y++)
 {
  servo=1;
  Delay_ms(2);
  Delay_us(400);
  servo=0;
  Delay_ms(18);
 }
 Delay_ms(1000);
}
void post8(void)
{
 beep();
 beep();
 beep();
 for(y=0;y<=30;y++)
 {
  servo=1;
  Delay_ms(2);
  servo=0;
    Delay_ms(18);
  Delay_us(700);
 }
 Delay_ms(2000);
 for(y=0;y<=30;y++)
 {
```

```
  servo=1;
  Delay_ms(2);
  servo=0;
    Delay_ms(18);
  Delay_us(700);
 }
 Delay_ms(1000);
}
void post9(void)
{
 beep();
 beep();
 beep();
 for(y=0;y<=30;y++)
 {
  servo=1;
  Delay_ms(2);
  servo=0;
  Delay_ms(18);
 }
 Delay_ms(3000);
 for(y=0;y<=30;y++)
 {
  servo=1;
  Delay_ms(2);
  servo=0;
  Delay_ms(18);
 }
 Delay_ms(1000);
}

void check_servo(void)
{
 if(ir1<=40)
 post1();
 else if(range1>=45 && range2>=45)
 post2();
 else if(range1>=70 && range2>=80)
 post3();
 else if(range1<=35 && range2<=35 && range3<=60 && range4<=80)
 post4();
 else if(range3<=25 && range4<=25)
 post5();
 else if(range3<=15 && range4>=35)
 post6();
 else if(range3>=35 && range4<=15)
```

```
 post7();
else if(range3>=100 && range4<=40)
 post8();
else if(range3<=40 && range4>=100)
 post9();
}
```