Design and data analysis for a belt-for-blind for visual impaired people

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Abstract: This research designs a new walking support system for the blind people in order to 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. In this research, a belt for blind 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 analysing 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. The developed belt for blind device is superior in terms of less weight less, able to detect stair and hole, low cost, less power consumption, adjustable, less training and availability of actuation systems. It was tested and implemented successfully to address all those issues.

Keywords: walking support system; belt for blind; blind people; terrain detection; obstacles avoidance.

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1 Introduction

Visual impairment is one of the most common disabilities worldwide. WHO estimated around 38 million blind people (WHO, 1997). In most countries of Asia and Africa, it accounts for over 40% 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. The largest number of visually impaired people falls into the senior citizen category; in fact 66% of people with impaired vision are over 75-year old (MoBIC, 1997; Lacey and Dawson-Howe, 1998; WHO, 1997). There are many blind people in Malaysia. 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 with non-electronics devices to help the blind people. Mobility is an ability of movement within the local environment with the knowledge of objects and obstacles in front. Blind individuals find their mobility difficult and hazardous, because of not identifying the obstacles easily for comfortable navigation. The autonomous navigation without collision and with discrimination of objects becomes the major task for their daily life. Since early 1950s 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).

Usually, to work outdoor, the blind people face difficulties. Therefore, many of them use a guide cane 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 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 a guide cane cannot detect any obstacle within the range of two to three metres and can only detect an object when it has a contact with it. If there is no contact, the user will eventually bump to it. It cannot detect any moving object and therefore are exposed to dangers of hitting vehicles or even moving animals.

Electric assistive technologies (EATs) provide the blind people spatial information about the environment in assisting for navigation. Early technology uses ultrasonic to detect the obstacles. Later, due to the developments in high speed computer and sensors, the efforts are directed to develop sophisticated and more intelligent ETAs. Most of the early ETAs were 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. 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 (Ifukube et al., 1991). Few sonic sensors are attached on normal eyeglasses, and their data, using a microprocessor and A/D converter, are down converted to a stereo audible sound, and headphones are being used to get feedback signal. Borenstein and co-workers developed Navbelt at University of Michigan (Shoval, 1993, 1994; Borenstein and Koren, 1985, 1988; Borenstein and Ulrich, 1997; Ulrich and Borenstein, 2001) as a guidance system, using a mobile robot obstacle avoidance system. Another patented device, the taking cane, has the ability to give speech output (Lofving, 1998; Hsieh, 1992). Smart shoe can detect an object a metre away by using an infrared sensor located on the shoe (Castle, 2003). 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 (Meijer, 1992). Sonic Eye works with the concept of mapping of image to sound (Reid, 1998). Kamel and Roth developed a GUESS system (graphics and user's exploration via simple Sonics) that provides interrelational representation of objects in a non-visual environment. Sainarayanan from University Malaysia Sabah developed an ETA to assist blind people for obstacle identification during navigation, by identifying objects that are in front of them (Sainarayanan, 2002). Similar robotic recognition related research has been done. Zhao et al. (2010) presents a new method for mobile robots to recognise scenes with the use of a single camera and natural landmarks. Wang et al. (2010) presented a new method of applying laser range finder to obtain road edge points in order to solve the road recognition problems of outdoor mobile robot. Hossain (2010) and Hossain et al. (2011) have provided detailed review on walking support system for the visual impaired people.

2 Problem statement

This paper addresses how to overcome those raised issues and propose an alternative belt-for-blind with design analysis, experimental analysis and implementation analysis. To assist blind person, correct technology could be used to overcome of the mentioned issues. Some of the technological achievements 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, a mobile robot uses sensors in order to avoid any obstacle. The technology can be used for a blind person to walk safely and reduce the danger when walking without a guide cane. When multiple sensors are installed on the blind person, 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. It is more economical to apply the technology directly to the person rather than buying a complicated robot. In this case, it becomes difficult to mimic nature in its entirety of human vision system. 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. A belt for blind is proposed, developed, tested and implemented for visually impaired people. Appropriate design parameters are identified accordingly. The walking support system will help the blind user to avoid obstacles in the way of his destination.

3 Design issues, setup and results

The design issues are addressed with 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.

3.1 Design guidelines

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 finalising 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 300 gm
- 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 (Blasch et al., 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-familiarisation 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.

Figure 1 Experimental setup with isometric view of the sensors on the supporting structure (see online version for colours)

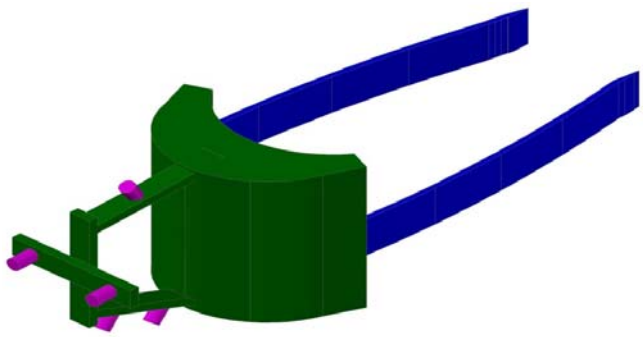
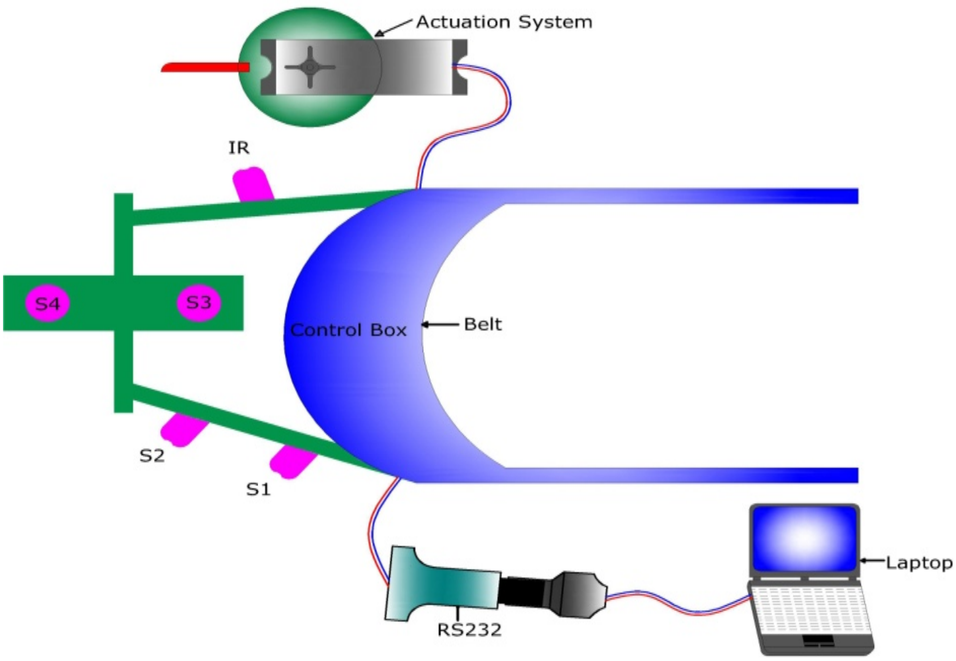


Figure 2 Experimental setup with actuator and data acquisition system to the wearable belt (belt-for-blind) with S1, S2, S3 and S4 ultrasonic sensors (see online version for colours)



The experimental setup designed based on the above criteria is shown in Figures 1 and 2. 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. The following components are used in the system (Figures 1 and 2):

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.

3.1.1 Selection of belt

This study emphasises 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 et al., 1998). This will distract the ultrasonic sensor's directivity, thus disrupts the readings taken from the ultrasonic sensors.

3.1.2 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.

3.1.3 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 40 kHz 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 shows the directivity of the sensor S1 or S2 while Figures 4 and 5 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 and Koren, 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 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.

3.2 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 (Figure 6). 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. 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 1. 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. Those experiments were conducted for data calibration before we started our design and the main aim was to check the stability of the sensor's reading. It was used for finding our desired data. Besides, those data are ideal value of used sensors that worked on lab for calibration and later used those sensors with calculated error as an offset. Besides, a mathematical model is developed that assisted 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.

Figure 3 Ultrasonic sensor tilted at an angle with the vertical axis (α = 30°) (see online version for colours)

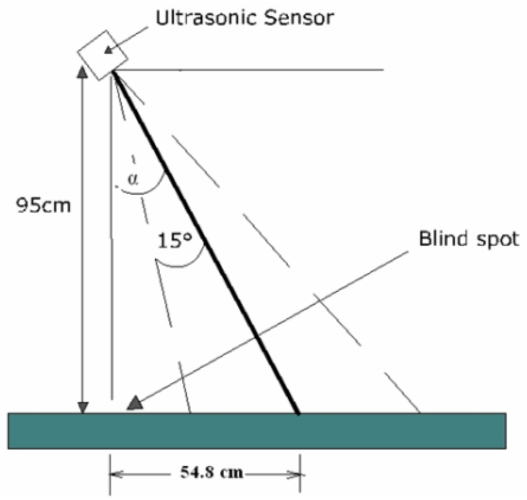


Figure 4 Ultrasonic sensor directed parallel to the ground (see online version for colours)

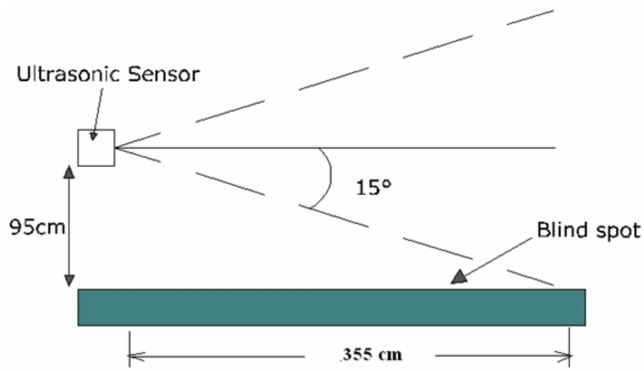


Figure 5 Directivity of ultrasonic sensor (see online version for colours)

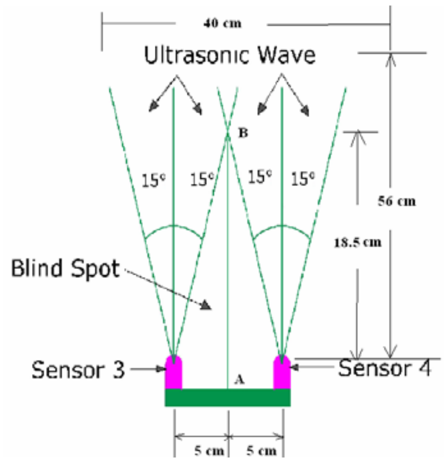


Figure 6 Calibration of experiment (see online version for colours)

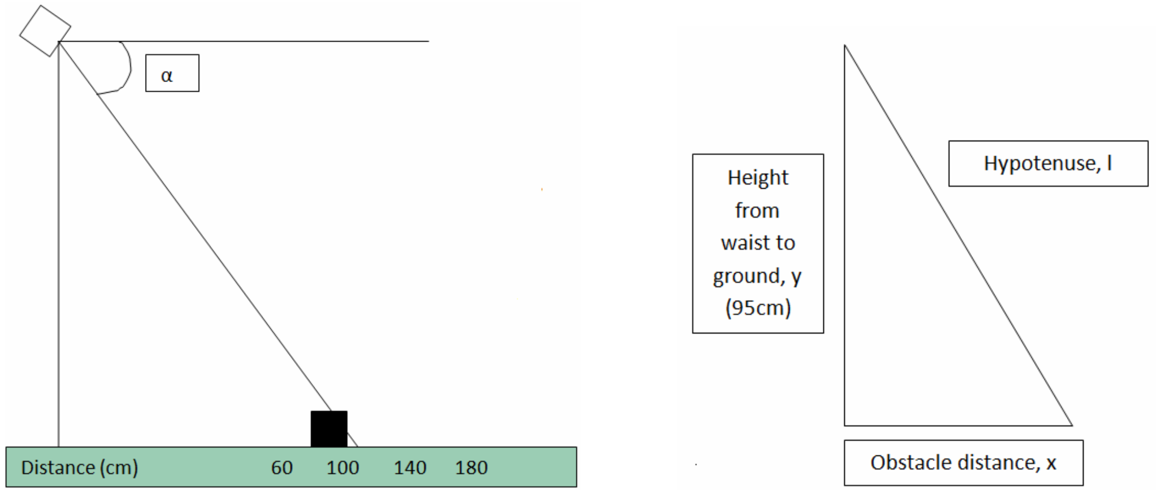
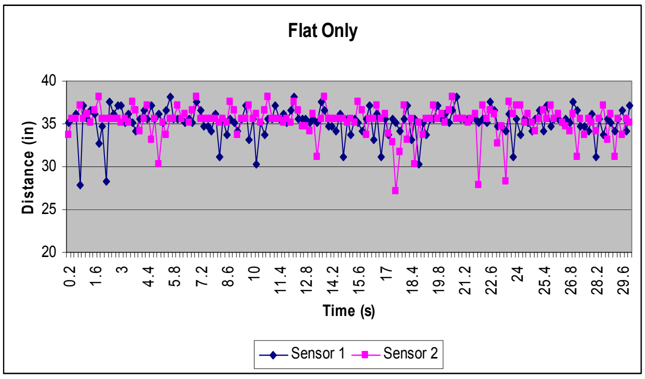


Table 1 Calibration results for horizontal distance

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

Figure 7 Ultrasonic sensor data read by sensors S1 and S2 (see online version for colours)



3.3 *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 2) in Figure 7 show almost constant distance between the sensors and the ground. Evidently these are distances of the hypotenuses as shown in Figure 5. Thus we can conclude sensor reading for these sensors in the range of 35 to 40 inches means flat ground in front. 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.

3.4 *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 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 12 cm and 30 cm 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 = * 95 cm – H * vertical distance between the sensors attached to the waist and the ground.

From Tables 2 and 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 Tables 2 and 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.

Figure 8 Experiment setup for detecting obstacle height

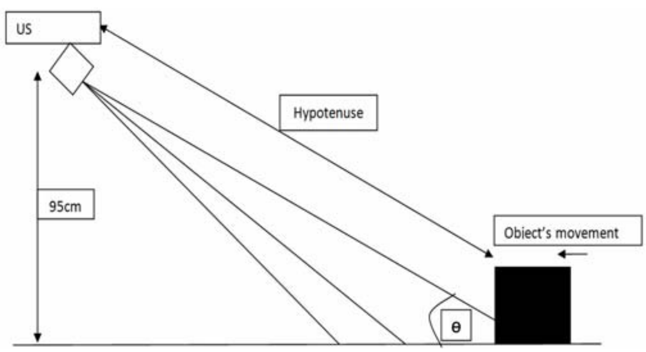


Table 2 Calculation for a 12 cm high object using sensor data

No.	*Distance (cm)*	*Hypotenuse (cm)*	*Angle, θ (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 Calculation for a 30 cm high object using sensor data

No.	*Distance (cm)*	*Hypotenuse (cm)*	*Angle, θ (degree)*	*Height H (cm)*	*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

3.5 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 7), however, the dataset shown in Figure 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. 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. Initially vibration effect of the sensor was not considered. However, we had lot of scatted data, from where it was too difficult to identify hole as an object. Later, we redesign our system and determine the less vibrate part of our body is waist. Besides, we consider certain offset or variation level to find out our scenarios more clearly.

3.6 Mathematical model

Figure 9 shows the stair 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. The angle was fixed. 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 (2.1):

$$X = h \tan \alpha \quad (2.1)$$

$$a = H \tan \alpha \quad (2.2)$$

Now if it is assumed H = 30 in, a = 30 in (almost equal to three steps of walking). Then equation (2.2) gives $\alpha = 45°$.

On substituting this value of α in equation (2.1) we get X = h.

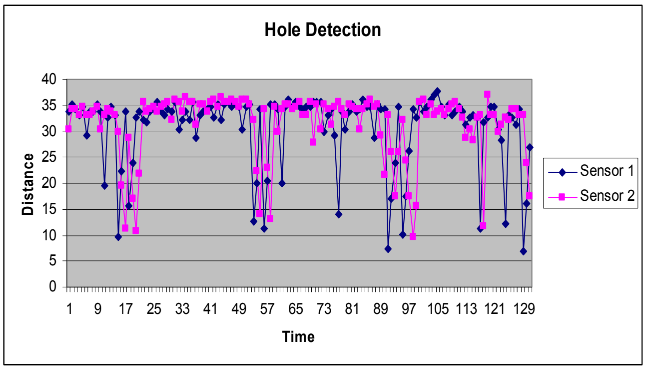
A standard unit rise of a stair is around 7.75 inch.

For a normal human, walking speed ‘v’ is about 40 in/s. Let the walking speed of a blind person behalf 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 $20 \times 0.39 = 8$ (approx.). From equation (2.1), we can see with increase of α the distance X increases. That means number of data could be increased using larger angle.

Figure 9 Hole detection (see online version for colours)



However, from Figure 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. Figure 10 illustrate the geometry:

$$C = h \tan \alpha \qquad (2.3)$$

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

Then equation 2.3 gives α = 26.56°.

Using this value of α in equation (2.2) we get a = 30 × 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 seven inches, which is just little bit smaller than one foot length. Then the distance travelled 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°. This will give five data in case of a stair up and four data in the case of hole or stair down.

Figure 10 Geometry of stair up for sensor by sensor S1 or S2

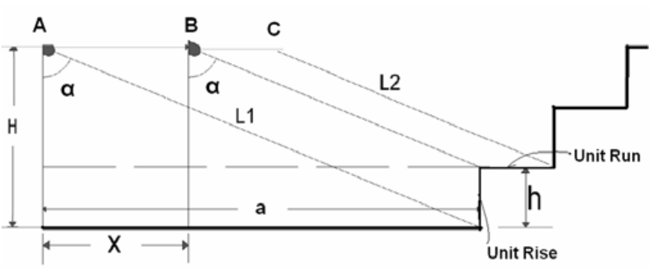
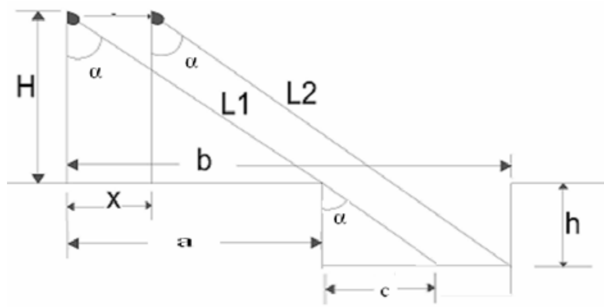


Figure 11 Geometry of hole for sensing data by sensor S1 or S2



3.7 Success in detecting hole

Based on the above mathematical model sensors S1 and S2 are placed at 30° with the vertical. This new orientation of the sensors helped in identifying hole ahead that are shown in Figure 12. Number of data at the hole is found to be quite low as predicted by the mathematical model.

Figure 12 Hole in front and hole detected with sensors S1 and S2 inclined at 30° with the vertical axis (see online version for colours)

3.8 GUI development

We have developed a GUI for data acquisition from the environments through the sensors using visual C programme (Figure 13). 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 (Figures 14 and 15). 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. 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. Instrumentation for acquiring terrain data is developed. 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.

Figure 13 GUI screen shows sensors and data (see online version for colours)

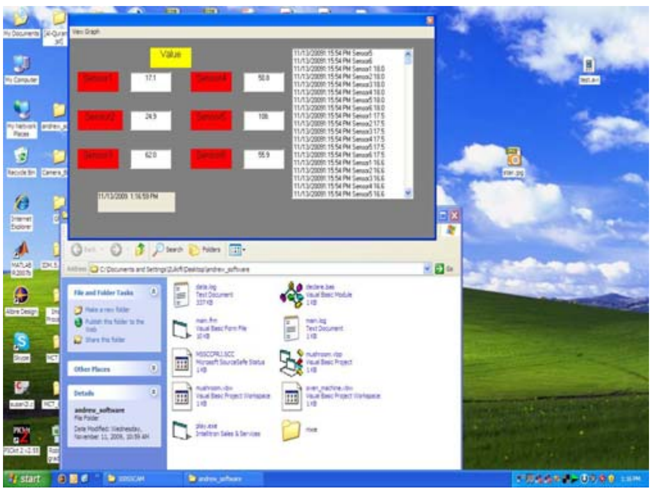


Figure 14 Circuit diagram of the system (see online version for colours)

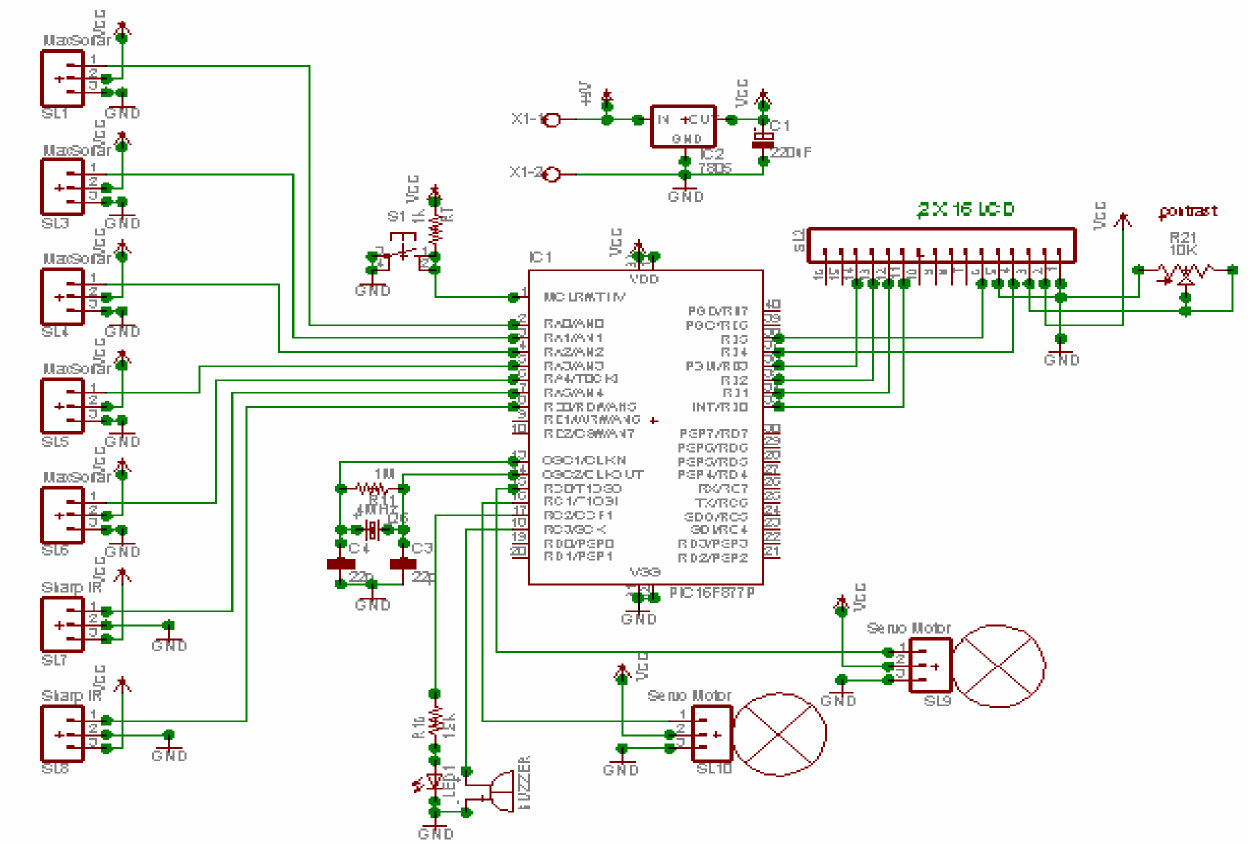
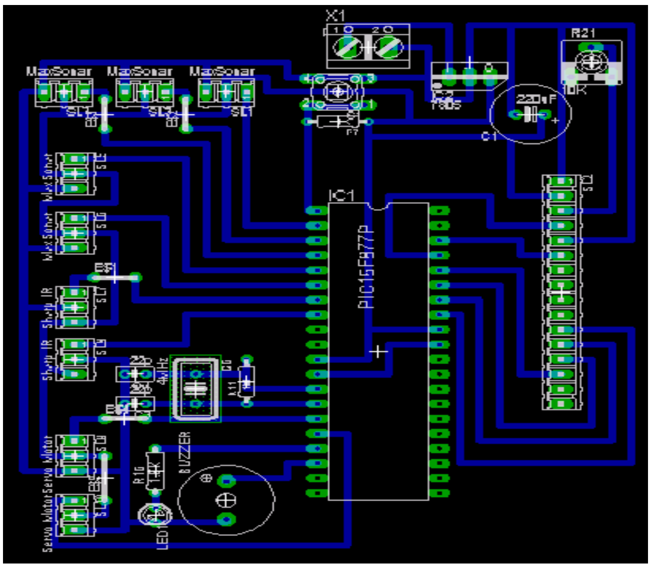


Figure 15 PCB layout of the circuital diagram (see online version for colours)



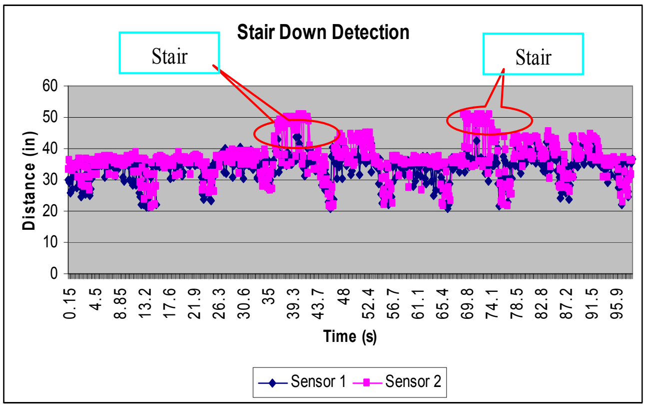
4 Experimental results

The experimental data on different terrains are analysed. Experiments conducted for terrain detection mainly uses the sensory system designed and developed mentioned earlier, 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.

4.1 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 16 before the detection of the edge of the stair, reading from both the sensors that are pointing toward the ground (S1 and S2) remains within a band of 35 to 40 inch. As soon as the sound wave 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, whereas readings of sensors S3 and S4 will remain unchanged. In Figure 16, data marked against detection of stair down is quiet distinct. From repeated experiments with steps of height nine inches this data ranges between 45 to 52 inches for sensors S1 and S2.

Figure 16 Beginning of a step leading toward down stair (see online version for colours)



4.2 *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 (Figure 17).

4.3 *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 18 shows photograph of drop off in front of a person while Figure 19 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.

Figure 17 Sensor data during climbing a stair upward (see online version for colours)

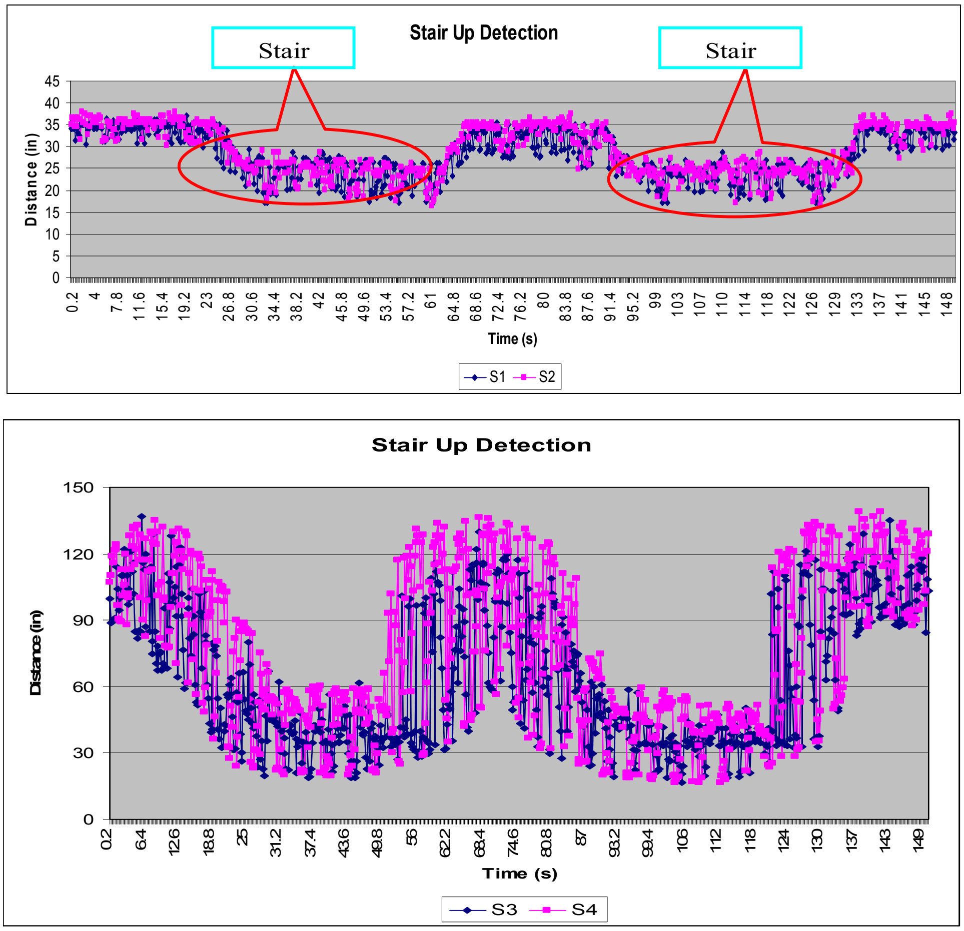


Figure 18 Photograph of drop off in front of a person (see online version for colours)

Figure 19 Sensor data on flat surface and at drop off

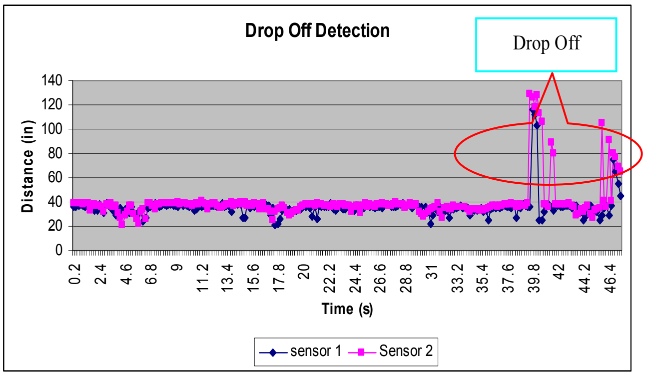
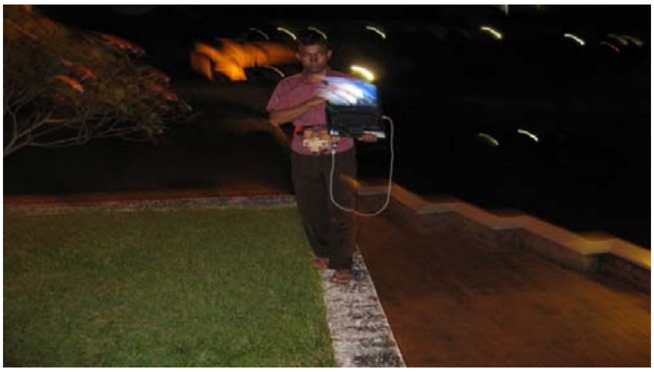


Figure 20 Photograph of drop off on the left side of a person (see online version for colours)



In Figure 21, 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 20, 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 22. 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. Figure 23 shows the sensor data.

Figure 21 Sensor data shown by sensors S1 and S2 (see online version for colours)

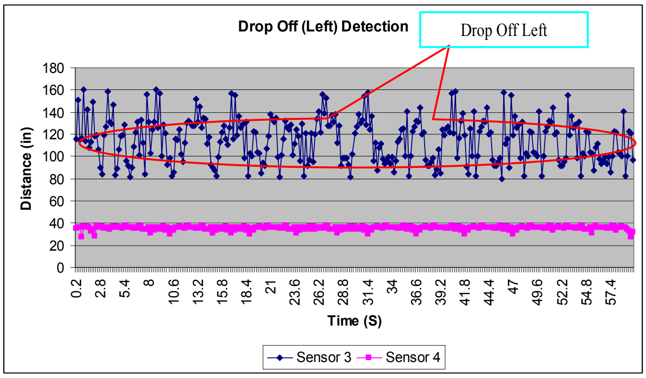
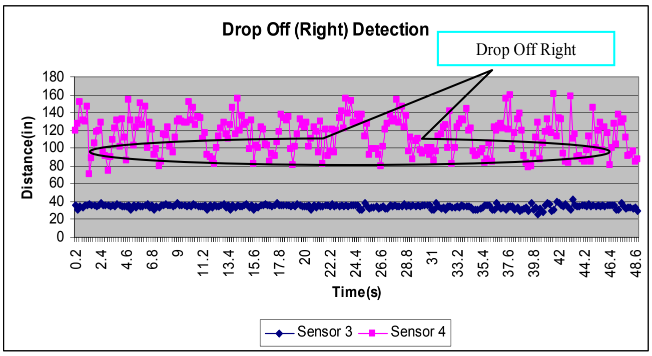


Figure 22 Drop off on the right side of a person (see online version for colours)

Figure 23 Sensor data shown by sensors S1 and S2 (see online version for colours)



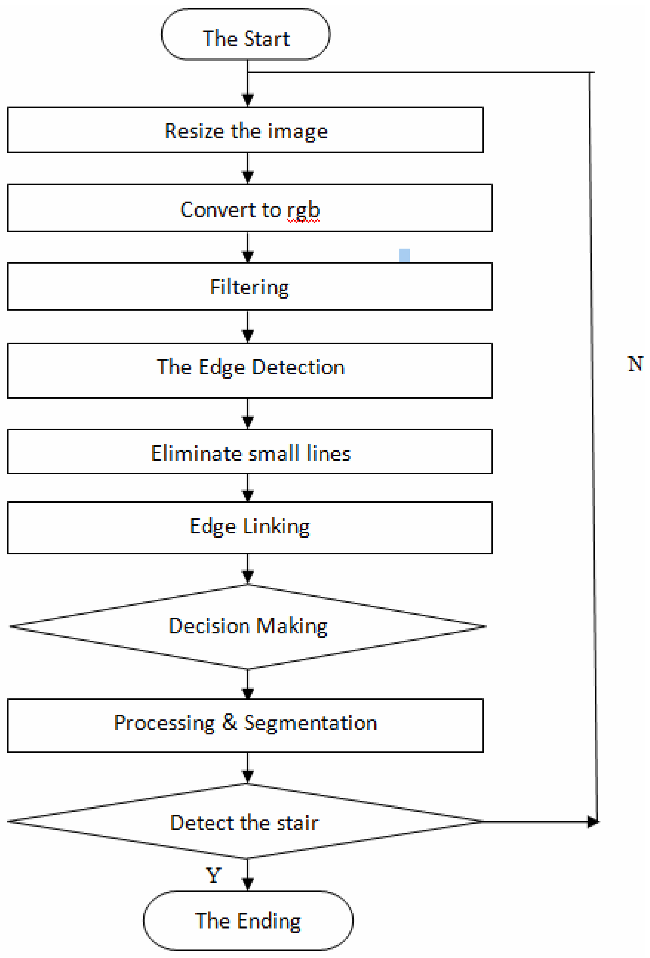
4.4 *Complex scenario*

In real life it is rare that all scenarios will appear as discrete maps as experimented above. In Figure 23 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.

4.5 *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 24 illustrates the whole flow of our algorithm.

Figure 24 The whole flow of the algorithm (see online version for colours)



4.6 *Algorithm 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 25 and 27 respectively, and their processed images for edge detection are shown in Figures 26 and 28 respectively. Photograph of a hole and its processed image are shown in Figures 29 and 30, respectively. It is clearly evident in Figure 29 that the there is no depth information available in the processed image that could lead to identification of the hole.

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. This chapter analysed 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 for developing blind support system hardware. Comparison tables are used for type of sensor used and type of camera used (Hossain et al., 2011a). The developed device is superior in terms of the following aspects: weight less than 500 gm, able to detect stair and hole, low cost, less power consumption, adjustable, less training and availability of both actuation systems.

Figure 25 Original image stair up (see online version for colours)

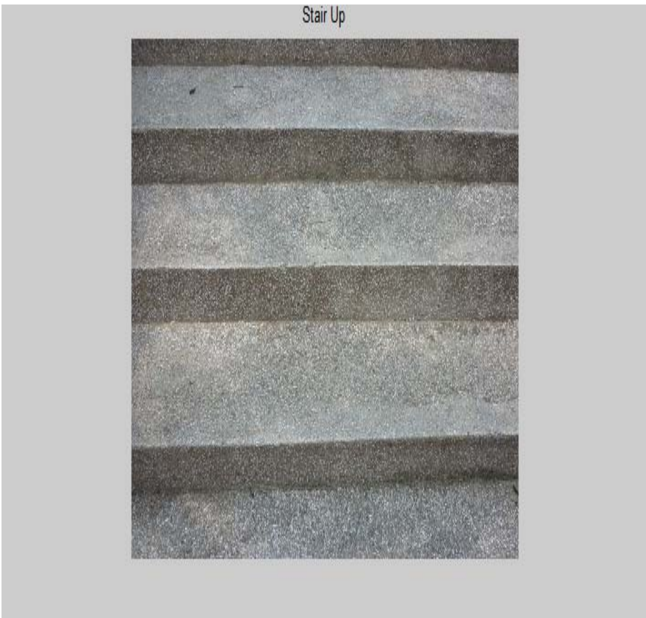


Figure 26 Extracting parallel stair up edges

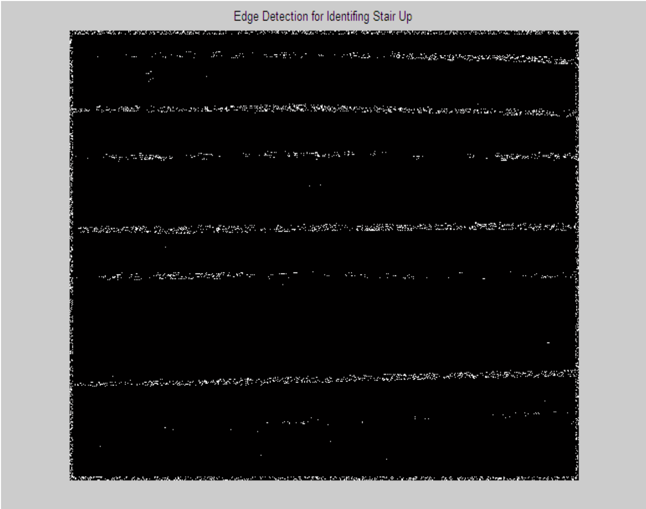


Figure 27 Original image stair down (see online version for colours)

Figure 28 Extracting parallel stair down edges

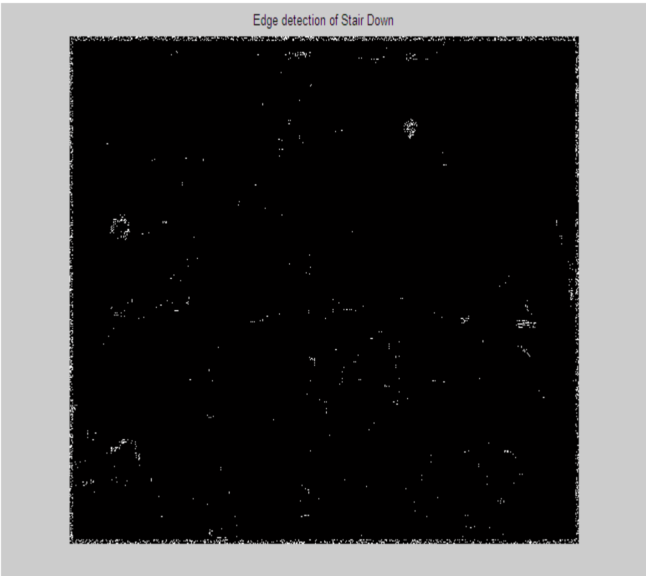


Figure 29 Original image for hole (see online version for colours)

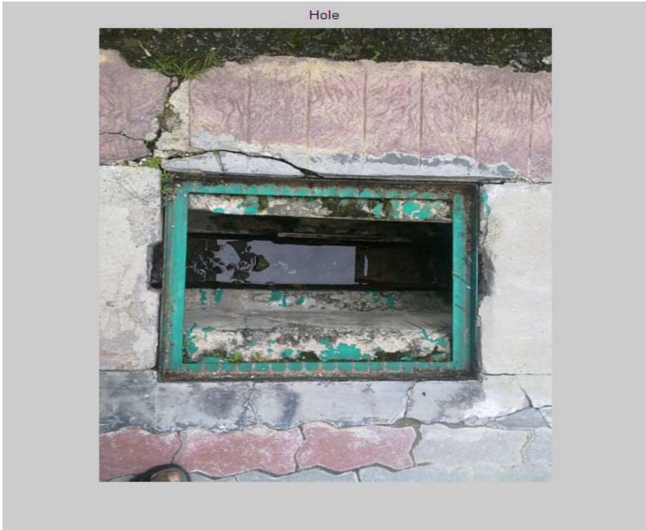
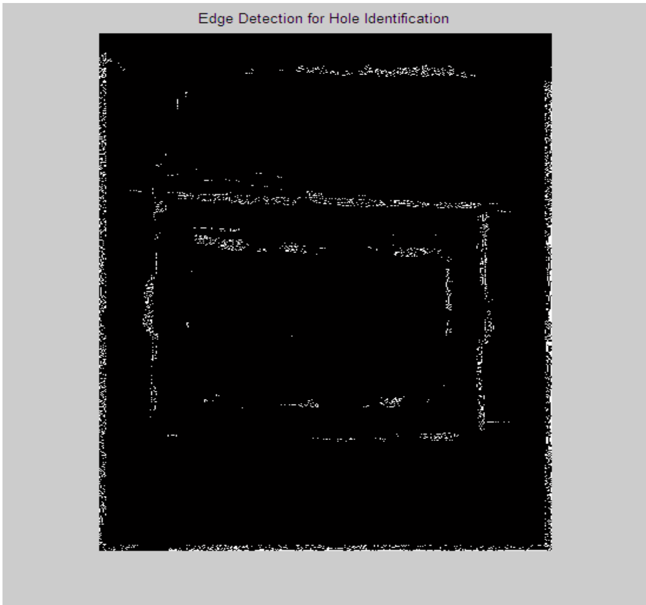


Figure 30 Extracting hole edges



5 Conclusions

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 and performance analysis. 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. Algorithms are developed through extensive experimentations that are able to differentiate different obstacles around the walkway of a blind person. A new walking support system for the visually impaired people named as 'belt for blind' is designed for detecting information about terrain where the environment consists of various obstacles such as stair, hole and so on. This deigned prototype cannot differentiate between animate and inanimate obstacles. So in further works it should consider this issue. To train scenario information better, neuron network could be applied.

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