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Stereo Vision-based Path Finder for Visually Impaired

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Abstract: This paper introduces a novel electronic mobility aid for visually impaired users that helps them navigate in any given environment and avoid knee level to head height obstacles. The mobility aid uses stereo imaging system to capture the images of the area in front of the user. The processing unit generates a disparity map and a segmentation algorithm extracts information about the relative distance of obstacles from the user. This information is relayed to the user in simplified vibration pattern feedback to inform the user of the path to be taken to avoid collision with the obstacle. Special hardware was designed to make the system portable and cost effective.The mobility aid was validated on 55 visually impaired users. The subjects walked in a controlled test environment with a varying number of obstacles placed in their path. The accuracy of the device to help the user avoid obstacles and the average speed of walking of the user were determined. The results obtained were satisfactory and the device has the potential for use in standalone mode as well as in conjunction with a white cane and thus help visually impaired people counter mobility problems.

***Keywords**: visually impaired, stereo, mobility, disparity, navigation*

I. INTRODUCTION

The visually impaired (VI) population is very diverse and can be characterized based on the degree of vision loss and age. According to a survey carried out by the World Health Organization (WHO) in 2010, 285 million people out of the total world population of 673 million are visually impaired [1]. Out of the VI population, approximately 39 million are completely blind and 246 million have low vision. It is estimated that visual impairment could triple due to population growth and aging by 2050. Vision impairment occurs due to conditions such as diabetic retinopathy, muscular degeneration, glaucoma, corneal clouding, *etc*. It can affect most day to day activities such as walking, driving, reading, recognizing objects, people, places, *etc*. Lack of mobility is one of the severe concerns for VI people. They find it extremely difficult to travel independently as they cannot determine their position and obstacles in the surrounding environment. One of the most commonly used mobility aid for navigation is the white cane. This device is affordable, light in weight, and can help avoid knee height obstacles.

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However, before using the white cane independently, the user requires to undertake approximately 100 h worth of training. This makes the process laborious for a new user. Also, the users have to continuously scan the area in front of them. Moreover, the white cane cannot detect obstacles that are midway between the knee and head height. Another commonly used mobility aid is a dog guide, which is similar to the white cane, i.e it can help avoid knee height obstacles. The costs incurred in training and maintaining a dog are very high (approximately $12000) [2]. Also, a dog guide can be used for a maximum period of 5 years. Moreover, a dog guide is not a convenient option for all VI people. For example, elderly VI people find it difficult to take care of the dog guide. A more advanced version of mobility aid is electronic travel aid (ETA). There have been many literature reports regarding the development of ETA. Few ETA's provide only information on the presence of obstacles and the user has to decide the direction to be taken to avoid a collision. Other ETA's provide information regarding the path to be taken post detection of the obstacles to avoid the collision. All ETA's typically use range sensors like ultrasound, sonar, or cameras. ETA's can be classified based on the type of range sensor used and the type of feedback given to the user. ETA's like Guidecane [3], CyARM [4] use ultrasound sensors for the detection of obstacles and vibrotactile sensors to provide feedback to the user. Navbelt [5] and FIU [6] use an ultrasound sensor for obstacle detection and stereo headphones for feedback. Some camera-based ETA's like ENVS [7], tactile vision system (TVS) [8] use stereo cameras for obstacle detection and vibrators for feedback. VOice [9], Visual acoustic space [10], NAVIG [11],use stereo headphones for feedback. All the above specified ETA's suffer from the following shortcomings:

- The travel aids are bulky as the processing is performed on a laptop or single-board computer;
- More number of range sensors are required to capture a wider field of view;
- The complicated feedback pattern leads to an increase in training time;
- The cost of each ETA is significantly high.

Knowing the limitations of the above-mentioned ETA's, there still exists a need to develop a fully portable, economic, compact, and reliable ETA, which ensures that VI people can commute independently and confidently. The present work proposes a design of a portable travel aid based on stereo cameras that can help detect obstacles in front of the user, calculate a path free of obstacles and help navigate the user along the free path to avoid collisions *via* vibrational and mono auditory feedback. Section 2 of the paper focuses on the hardware design of the prototype.

Section 3 describes the device operation. Section 4 explains the software module of the travel aid. Section 5 provides specifics about the experimental arrangement, observations, and results. In the end, section 6 highlights the major findings.

II. ELECTRONIC HARDWARE

The electronic system architecture of the mobility aid is shown in Figure 1. The key component of the mobility aid prototype is a 200 pin raspberry pi compute module which has an

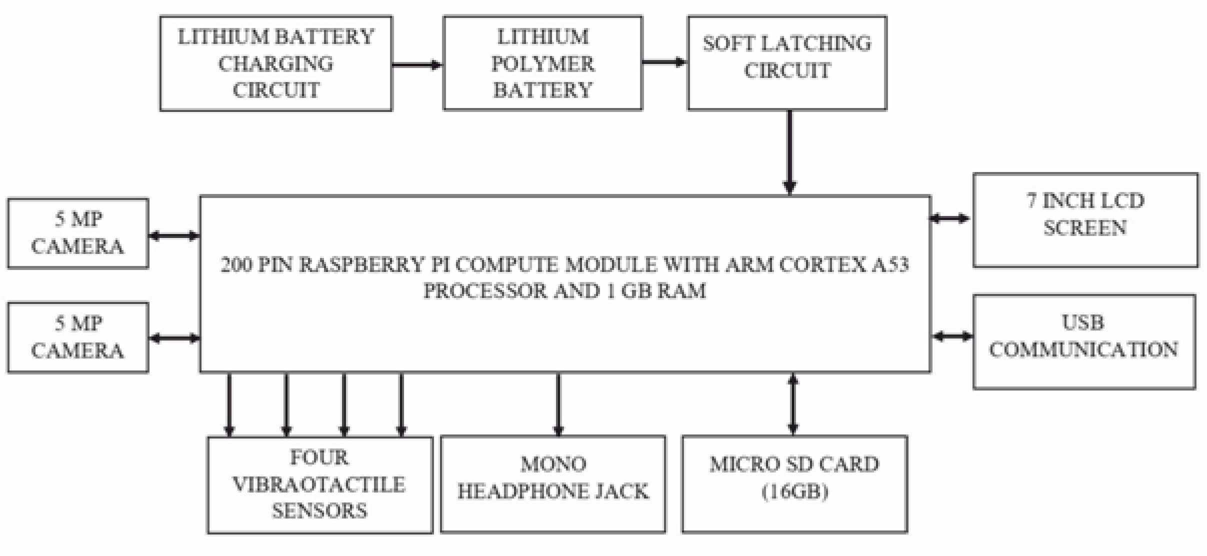

Figure 1 : Hardware deisign of mobility aid

ARM cortex A53 processor and 1GB RAM. This module runs the basic Linux operating system, which is stored on a microSD card. A 3500 mAh lithium (Li)-polymer

the battery is provided on the prototype, which can power the device for up to 8 hours. The board has an inbuilt charging circuit that charges the Li-polymer battery, taking approximately 6 hours. Two identical 5-megapixel cameras are interfaced to the module using a camera serial interface. The positioning of the cameras is based on interpupillary distance (IPD). IPD is defined as the distance between the centres of the pupil. It is an important measure in the stereoscopic world. According to the ANSUR database comprising of 2382 subjects, it was determined that the mean IPD of men and women is 62 to 64 mm. Appropriately, a 63 mm distance was set between the two cameras in the prototype. The stereo cameras along with the processing unit and Li-polymer battery are attached on to the front or outer side of the orthopedic belt as shown in Figure 2

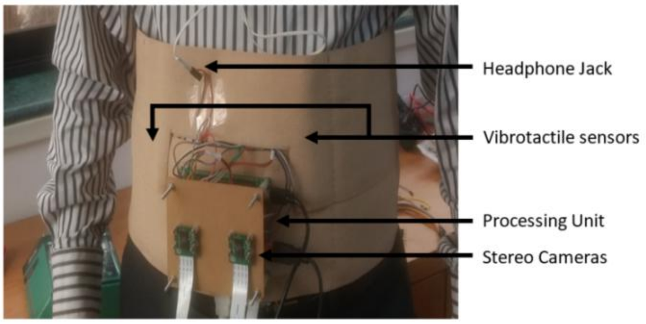

Figure 2 : Arrangement of hardware components on the front side of orthopaedic belt

Two coin-sized vibrotactile sensors, each of 9000 rpm and 3 volts operating voltage are connected to the device for vibratory feedback. These vibrators are fixed on the inner region of the orthopedic belt. The hardware and software can support up to 8 vibrotactile sensors. The arrangement of these vibrators is as shown in Figure 3. In addition to the vibratory feedback, one mono head jack is provided for auditory feedback on the front side of the belt. A USB port is provided for data transfers. A 7-inch LCD interface is provided on the board for use during the training phase and is disconnected during the validation process.

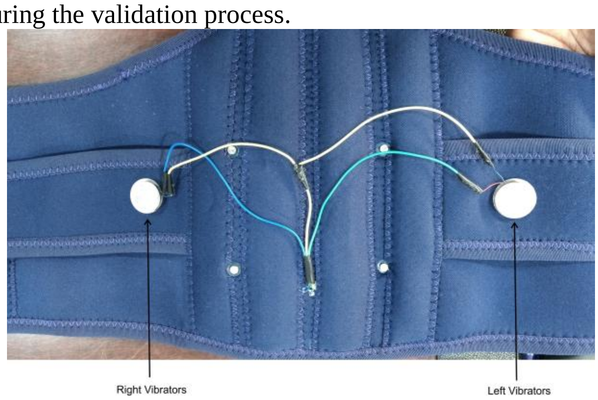

Figure 3 : Arrangement of vibrators on inner side of orthopaedic belt

III. FUNCTIONAL DESCRIPTION

The belt containing the device is tied around the user's waist in a similar manner to a regular orthopedic belt. The cameras have a vertical field of view of 49° and a horizontal field of view of 63°. Taking into consideration the average height of a person as 1.75 m, the device can detect knee level to head height obstacles. The relative distance from the user must be greater than 2 m and it can detect obstacles up to 7 m. When the system is turned on, the cameras start capturing stereo images of the area in front of the user and the obstacle detection and avoidance algorithm detects obstacles in the captured images and calculates the path devoid of obstacles.

This information is given to the user via vibrators. As shown in figure 3, there are two sets of vibrators, left vibrators to inform the user to turn left and right vibrators inform the user to turn right depending on the position of obstacles. Scenarios:

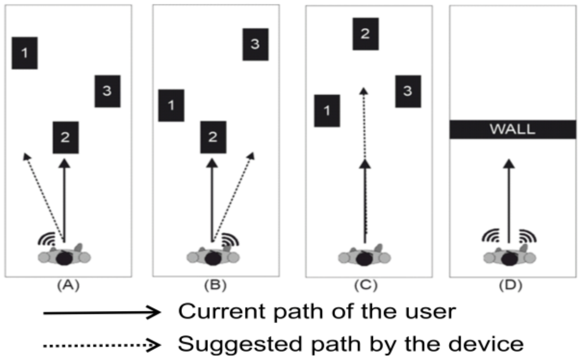

Figure 4: Scenerios encountered by mobiltiy aid

- Consider the arrangement of obstacles as shown in figure 3(a). The algorithm will identify three obstacles (1, 2 and 3) along with the closest and the furthest obstacle to the user that are obstacle 2 and 1, respectively. In this scenario, the left vibrators will start vibrating informing the user to turn left.
- As shown in figure 3(b), the algorithm again detects three obstacles but this time the obstacle 3 is furthest to the user and hence the right vibrators start vibrating informing the user to turn right.
- If obstacle 2 is furthest to the user as shown in figure 3(c), then there is no vibration thus informing the user that it can continue traveling in the current direction.
- In some situations, the user can come in front of an unavoidable obstacle like a wall or a closed gate as shown in figure 3(d), in such situations both set of vibrators will vibrate informing the user that he cannot move ahead.

The vibration pattern and action to be taken are as given in table 1

Table 1: Vibration pattern and corresponding action

Vibration pattern	Action to be taken by the user
Left vibrators vibrate	Turn left
Right vibrators vibrate	Turn right
No vibration	Travel straight
All vibrators	Cannot move ahead. Turn around

IV. OBSTACLE DETECTION AND AVOIDANCE ALGORITHM

The software architecture of the prototype is as shown in figure 5.

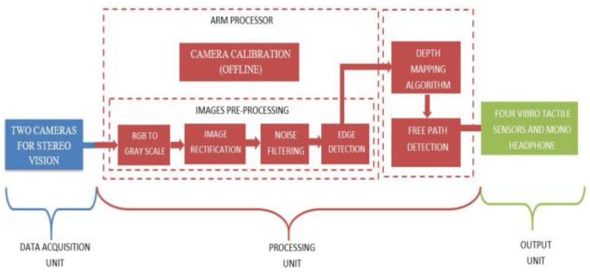

Figure 5 : Software architecture of mobility aid

The processing of the captured stereo images is performed on the ARM cortex A53 processor. To increase the accuracy of obstacle detection and provide correct vibrational feedback to the user, camera calibration process is performed when the user uses the prototype for the first time. The 9x6 checkboard image is used to perform the calibration process. When the user turns on the prototype for the first time, camera calibration module captures 50 stereo images of the checkboard (different orientation for each image). Some of the stereo images of the checkboard are as shown in figure 6.

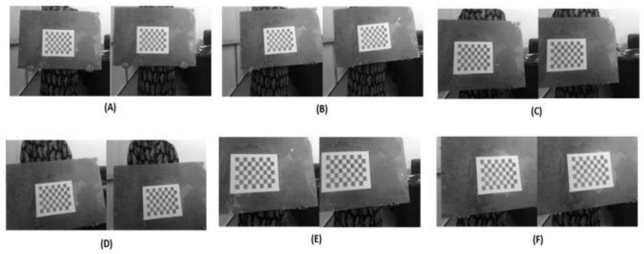

Figure 6 : Stereo checkboard images captured for calibration of cameras

OpenCV camera calibration module is used to calculate the rectification matrix for images captured *via* the left and right cameras. This process is repeated ten times and average rectification matrices are stored in the system memory of the users' device.

Stereo cameras capture images at a rate of 1 frame/second and each image has a resolution of 640x480x3. Pre-processing is performed on captured stereo images which include the following: a) RGB to greyscale conversion, b) image rectification using the rectification matrices obtained during the calibration process, c) bilateral filtering to enhance the edge information and remove noise; and d) canny edge detection algorithm to extract edge information from stereo images.

Post-pre-processing, the first step in obstacle detection and avoidance algorithm is generating the disparity map. The disparity map is an image that encodes the information of the relative distance of obstacles from the user in terms of a grey scale. The obstacle that is closest to the user is encoded as white and the obstacle furthest to the user is encoded as black. The algorithm architecture of the disparity map is as shown in figure 7

Figure 7 : Step to generate disparity map from stereo images

The disparity map algorithm uses the edge detected images captured by the left and the right cameras to establish the pixel correspondence. Working on edge detected images helped to increase the processing speed. Sum of absolute difference is used to establish this correspondence.

$$SAD(x, y, d) = \sum_{(x,y)\in d} |I_l(x, y) - I_r(x - d, y)|$$

where
I_l and I_r – left and right image respectively
x,y – pixel location of each image
w – window calculation of sum of absolute differences
d – distance of pixel from current location
For the given image resolution of 640 x 480, the window size of 9 x 9 gave the optimum results. Image rectification helps to perform only a 1-dimensional scan, i.e. scan along the x-axis to establish the correspondence. Preliminary experiments suggested that the obstacles that are at a distance of 7 m and above have a disparity of 27 pixels and obstacles with a distance less than 2 m have a disparity of 110 pixels and more. Thus, a horizontal scan to establish the correspondence was performed by varying the value of d between 0 and 110. This generated 111 pixel pairs in total and the winner takes all method was implemented for selection of the pixel pair with a minimum sum of absolute difference. The distance between the selected pixel pair is stored in the disparity map image at the pixel location the same as that of the left image pixel. At this point, the disparity map was established only along the edges. A bicubic interpolation technique was applied to calculate the disparity at other non-edge locations in the image. The disparity map obtained at this point has a pixel value between 0 and 110. Accordingly, to enhance the image quality, linear mapping was used to obtain a disparity map with pixel values between 0 and 255. Calibrated stereo images and the corresponding disparity map is as shown in figure 8

Figure 8 : Stereo images with calculated disparity

Obstacle detection and avoidance algorithm segments the disparity image into four sections as shown in figure 9

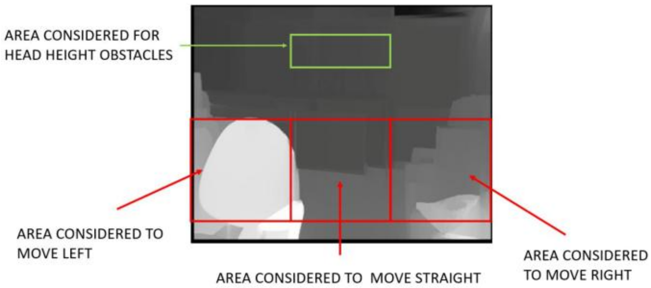

Figure 9 : Segmented areas of depth map for obstacle avoidance

The obstacle detection and avoidance algorithm consist of two parts: a) detection of obstacles from knee to chest level; and b) detection of obstacles from chest to head level.

a) Detection of obstacles from knee to chest level

As shown in figure 8 three areas marked in red are used to detect knee level to head height obstacles. Each red segment calculates the mode. The segment (containing obstacles) having the minimum value of mode is furthest from the user. The processing unit generates the vibration feedback ccordingly. The algorithm for the obstacle detection and avoidance is as given in table 2

Table 2 : Knee level to chest height obstacle detection and avoidance algorithm

	Input: Disparity map
	Output: Vibrotactile and auditory feedback
1	Extract three areas from the disparity map
2	Calculate the mode of each extracted area
3	Find the position of minimum mode value
4	Find the minimum mode value of three mode values
5	**If** minimum mode is greater than 130
6	Auditory feedback alerting user that there is no free path in front of them
7	**Elseif** position = left red area
8	Left vibrators will start vibrating indicating the user has to move left
9	**Elseif** position = central red area
10	No vibration feedback. User can move in the current direction
11	**Elseif** position = right red area
12	Right vibrators will start vibrating indicating the user has to move right

b) Detection of obstacles from chest to head level

As shown in figure 8, one area marked in green is used to detect chest to head height obstacles at a distance of 2 meters from the user. The processing unit calculates the mode of the area of the image within the green box. If the mode value exceeds the threshold value, then the processing unit generates vibratory feedback to change direction. The algorithm to detect chest to head height obstacles is as given in table 3

Table 3: Head height obstacle detection algorithm

	Input: Disparity map
	Output: Auditory feedback
1	Extract the area 20:40 rows and 161:300 columns of the disparity image.
2	Calculate the mode of each extracted area
3	**If** mode is greater than 100
4	Auditory feedback altering user that a head height obstacle is present in his current path

V. RESULTS AND DISCUSSION

The performance analysis of the prototype was evaluated based on three categories: 1) Time required to train the user to understand the vibration pattern. 2) Average time required for users to cover a fixed distance with a different number of obstacles. 3) Accuracy of obstacle detection and avoidance.
The prototype was tested on 55 VI users with ages ranging from 15 to 50 years. All the tests were conducted outdoor. The test design had the user navigate through the cluttered area. In the training session, the users were asked to wear the prototype around their waist.

The first part of the training involved giving users random vibration patterns and the response was recorded. The training time and the accuracy of response to vibratory patterns were recorded. The user was then asked to walk on a road of length 30 m and width 15 ft. The average time of navigation, the accuracy of obstacle detection and avoidance and percentage of false detection of obstacles were calculated under three different situations: 1) no obstacle in front of the user 2) two obstacles in front of the user 3) five obstacles in front of the user. All the obstacles in the experiment were stationary. The arrangement of obstacles on the road are as shown in figure 9

Table 3 : Training time of 50 VI users

Age group	Male users	Female users	Average training time (mins)
15-20	5	15	25.5
21-35	15	7	26.5
36-50	10	3	26

Table 4 indicates the average time required to train the users to respond correctly to the given vibration patterns (≥95%).

Table 4 : : Average speed of travel and percentage accuracy of obstacle avoidance

Age group	Male users	Female users	Average speed(m/s)	Accuracy
15-20	5	15	0.62	95.60%
21-35	15	7	0.6	95.00%
36-50	10	3	0.63	95.40%

Table 5 indicates the average speed of the user to commute from point A to point B under different conditions as explained in figure 9 and percentage accuracy of user to avoid the obstacles. Average speed is given in m/s.

It was determined that the average time required to train a VI person to understand the vibration feedback and to correctly respond to the given feedback was approximately 30 mins. It was also observed that the users could easily avoid obstacles and the accuracy of avoiding collision with obstacles was approximately 95%. The average walking speed of VI person while using the designed mobility aid was 0.6 m/s which is very close to the average at which the normal vision person walks i.e 1 m/s (average).

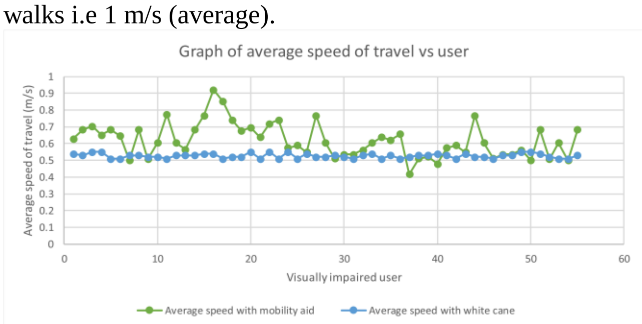

Figure 10 : Average speed of user using designed mobility aid

The average speed recorded for each visually impaired using designed mobility aid was compared with the average speed for visually impaired using a white cane. The graph of observation is as shown in figure 10. It was observed that there was an approximate 63% improvement in average speed and around 72% improvement in obstacle detection and avoidance. The users reported that the feedback pattern was very easy to understand.

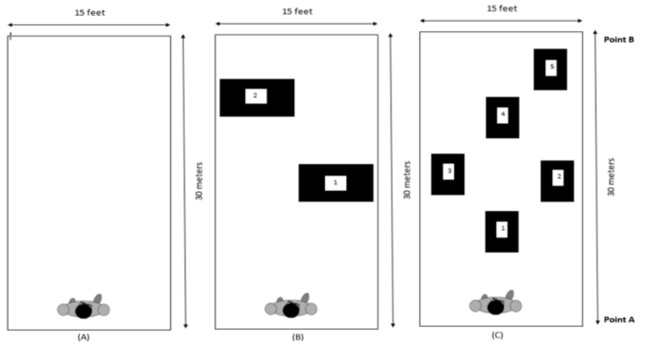

Figure 11 : Arrangement of obstacles for prototype validation

VI. CONCLUSION

In the present work, a computer vision-based electronic mobility aid for visually impaired people was successfully developed. This device facilitates the detection and avoidance of obstacles positioned anywhere between knee-length to head height. This device provides a wider field of view compared to the existing devices, which greatly reduces the need for active area scanning prior to walking. The whole device weighs approximately 465 g and the battery can last up to 8 h, which makes it portable as well as convenient to use. The device was tested on actual visually impaired people in controlled environments. The average mobility of the visually impaired users was determined to be very near to the mobility of a regular person with the help of this device. The subjects had very positive feedback with regards to the applicability of the device in their daily routine. This device used together with a white cane provides a promising solution for visually impaired people.

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