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Sensing Environment through Mobile: A Personalized Wearable Obstacle Detection System for Visually Impaired People

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Abstract—The challenge of improving the mobility of visually impaired people is still exist in the world even after proposing various types of solutions. This paper presents a wearable obstacle detection approach which can be personalized along with the user through a mobile device. The time of flight characteristic of a sonar wave has been used to identify the obstacles while several methodologies are proposed to classify the identified obstacles. The direction and the distance to an obstacle are informed to the user as a vibration feedback pattern. The approach can be personalized according tocharacteristics of the user such as user's height, vibration sensitivity, etc. A prototype of this approach has been used to conduct user evaluation experiments which were carried out in an unknown structured environment. Further analysis on familiarization process of this system, obstacle identification and confusions, comparative analysis between white cane and the system and effects of personalization to mobility were executed in order to gauge the effectiveness and the accuracy of the approach. The results of the evaluation have proved that the personalized system facilitate to improve the mobility of visually impaired people while giving an apparent consideration on the 3D environment.

Index Terms— Echolocation, Obstacle Detection, Personalized, Visually Impaired.

I. INTRODUCTION

According to the WHO statistics 285 million people are visually impaired worldwide and about 90% ofthem live in developing countries [1]. While ordinary people experience the new technologies and make their day to day life much easier, people who are visually impaired still do not have a proper way to feel and see the world. Currently there are several methods which have been identified to help visually impaired people but they may not be the most appropriate way which benefits them.

Compared to visually unimpaired people, it's a well-known fact that it is really hard for a blind person to move through an unknown environment [2]. Visually impaired people use their auditory sense to detect obstacles and localize them [3]. But it is really hard for them to focus where the obstacle really is. To avoid this issue lot of tools are built to assist them. Among these tools most known aid for visually impaired people is walking canes which use a tactile feedback to sense and detect obstacles within a short range. Other well-known option for visually impaired people to navigate their path isto obtain the help of a trained guiding dog. They can help their master to find obstacles and travel without any trouble, but the cost is high.

The dog has the ability to detect complex situations such as cross walks, stairs, and potential dangers, know paths, etc. Most of the information is passing through tactile feedback by the handle fixed on the animal. The user has ability to feel the attitude of his dog, analyses the situation and also give him appropriate orders. But guide dogs are still far from being affordable because it cost around the price of a nice vehicle. And also their average working time is limited. It is an average of 7 years [4].

Human echolocation is a human ability to detect objects bysensing the echo sound from the objects. But if it is to be used with visually impaired people, then they should be trained to detect those echoes [5]. In the real world, bats and dolphins use bio sonar ping to detect objects. If bats and dolphins use ultra-sonar to detect obstacles, the same methodology should be able to be adopted by devices such as mobile devices to aid the visually impaired people in navigating. This is the main motivation fact for this research.

This study discussed prototype of a personalized wearable obstacle detection system for visually impaired which can be used for their mobility improvement in day to day life. This prototype use sonar echolocation for sensing environment. To aware user about obstacles which are located his front view, this device uses vibration tactile feedback. Personalization of this wearable obstacle detection system can be done through a mobile device according to user's suggestions and needs.

The remainder of this paper is structured as follows. InSection II this paper reviewed the related work in current obstacle detection approaches for visually impaired. Section III presents the design of personalized wearable obstacle detection system and in Section IV the implementation of this system is discussed. Experiments of this study and the results are presented in Section V. Conclusion of this paper in Section VI and finally this study concludes the paper with future work in Section VII.

II. RELATED WORK

There are lots of researches done on navigation aid for visually impaired peoples. Normal people identify environment with their sense of vision, so most researches try tofind a navigation aid for visually impaired people with this sense of vision. A multi-modal electronic travel aid device [6] was presented by Fusillo et al. their study describes an electronic travel aid device which may enable blind persons to "see the world with their ears". This wearable prototype was assembled using low-cost hardware such as earphones, sunglasses fitted with two micro cameras, and a palmtop computer. There are some alternative solutions for vision based obstacle detection. Some of those researches were mainly

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focused on mobility solutions by using laser rays, Infrared, RFID, ultra sonar sensors, etc. Hesch et al. presented an indoor human localization system for the visually impaired people which are a laser based obstacle detection system [7]. They implemented a prototype approach, which consists of a pedometer and a standard white cane, on which a laser range finder and a 3-axis gyroscope have been mounted.

Laser based obstacle detection is not an affordable solution for users. However according to S. modi study [8] shown laser ray leads to high accuracy when compared to other avail- able methods. Some of researches have in cooperated RFID technology to make a navigation aid for visually impaired. Kulyukin et al. studies a RFID tag based obstacle detection approach in an indoor environment [9]. This work used RFID tags on the indoor environment and after that it can be sense through RFID technology and their work cannot perform well when pass walking.

Pathsounder [10] by Russel was one of the most primitive ultrasonic travel aids. It used pair of ultrasonic transducers which were mounted on a board that the user wears around the neck and it is located at chest height. This component provides only three separate levels of feedback, approximately indicating distances to relevant objects. User does not need to scan the environment physically but chest movement is the possible search strategy. The smart cane [11] presented by Singh et al is similar to walking cane physically and this Smart cane embeds a sonar sensor which can detect obstacles earlier and inform it to the user through a tactile feedback. This can be used to increase the obstacle awareness of a user however this is not a hands free solution. For the user this only improves obstacle awareness of the environment.

Showal et al. introduced ultrasonic based electronic travel aid (ETA) NavBelt [12]. The NavBelt consists of a belt, a small computer worn as a backpack and an array of ultrasonic sensors. The backpack used to process the signals inward from the sonar sensors, after then it applies the obstacle avoidance algorithms and sense them to the user through stereophonic headphones. In order to perform this stereo imaging techniques were adopted. This may not be a good solution as it is inconvenient for the user. Visually impaired people sense the environment through their ears most of the time. Acoustic feedback interfere the connection the visually impaired person has with the sound cues from the environment and reduces the person's ability to hear the essential cues. In their experiments they found that walking pattern of the user affects the accuracy of detecting obstacles because the sonar sensors can swing while walking. Guide Cane [13] by Borenstein et al. is a mobile robotics aid for visually impaired people. This robot embedded to a stick which can detect obstacles by multiple sonar sensors.

This robot equipment can itself navigate through paths and user can follow this robot. This approach is more similar to a Guide dog.

Hashino et al. study finds out a technical possibility ofusing ultrasonic sensors for guidance system aid visually impaired people to cross a road without doubt and unharmed [14]. Wearable obstacle detection for visually impaired [15] by Cardin et al. is a more similar approach to this research. This work presents an obstacle detection system for visually impaired people. Visually impaired user can be notified of any closed obstacles in range while moving in their environment. The system intends to detect the nearest obstacle through a stereoscopic sonar system and responds back with vibro tactile feedback to notify the user about its location. Cardin et al. improve their work to cover a large area in the front of the user [16]. This improved system uses 4 sonar sensors and 8 vibrators, one micro controller and a PC for calibration needs. According to the position of the sensors and actuators, the vibro tactile gives feedback after calculations.

III. DESIGN

The proposed methodology focuses on developing an adaptive system which detects obstacles along the moving path. Because this system targets the visually impaired people, the design basically flows with sound and vibration. The basic design approach can be divided into three parts and are discussed. The first part relates to the emitting sounds which can generate an echo, the next part is related to capturing the echo and generates a proper feedback and finally the last part is to personalize this wearable obstacle device with a calibration tool.

This study does not attempt to identify all obstacles in anenvironment. In this approach, it assumes that this is used only in a less obstructive indoor environment. The system works accurately under room temperature, because in this project sonar sensors distance measurement is calculated under room temperature. This project is not suitable to be used by more than one user simultaneously under maximum scanning range of sonar sensors.

A. System Architecture.

This system is embedded into a wearable belt which holds sonar sensors, vibration motors, arduinomega 2560 board and a Bluetooth module. In this design it uses 4 modules as to sense the environment and produce feedback to the visually impaired user. Sensing module, Signal Processing Module, Feedback Module and Calibration Module are those 4 modules. To get user inputs and calibrate the system according to the preferences of the user, mobile device works as a calibration tool. Following figure 1 illustrates high level design architecture of the system including all the main modules.

IV. SYSTEM'S SUB-COMPONENTS

In this section functionalities of all the main modules are described and discussed. These modules use different kind of hardware components to fulfill their tasks, each of these devices have also been described in following sections.

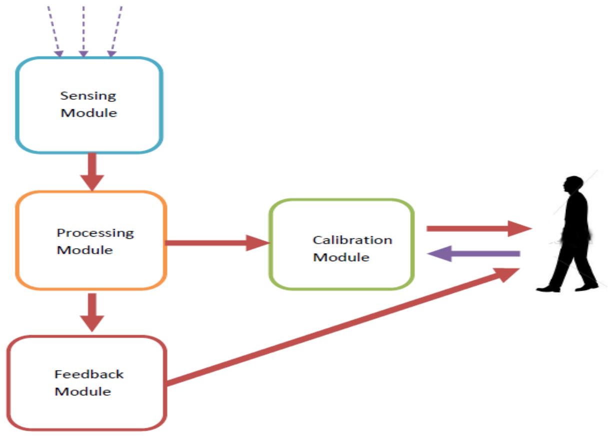

Fig. 1. System Overview

A. Sensing Module.

This system is embedded into a wearable belt which holds sonar sensors, vibration motors, arduino mega 2560 board and a Bluetooth module. In this design it uses 4 modules as to sense the environment and produce feedback to the visually impaired user. Sensing module,Signal Processing Module, Feedback Module and Calibration Module are those 4 modules. To get user inputs and calibrate the system according to the preferences of the user, mobile device works as a calibration tool. Following figure 1 illustrates high level design architecture of the system including all the main modules.

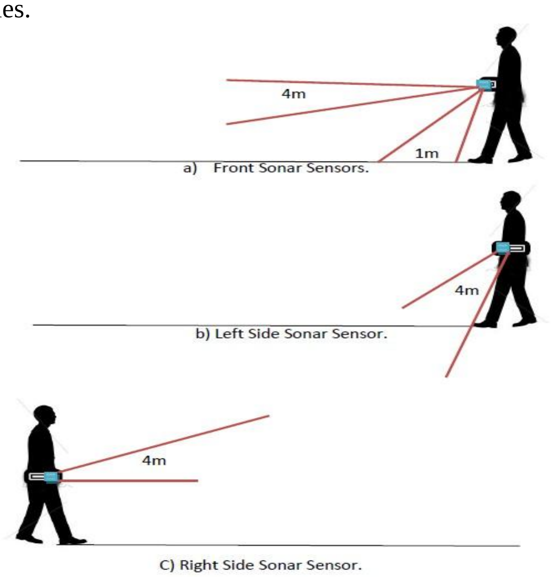

Fig. 2.Scanning process of embedded sonar sensor.

B. Signal Processing Module.

Input sonar echo signals which carry distance data are processed by a micro controller processing module. The system uses arduino mega 2560 to process all sonar echoes and generate outputs. The arduino Mega 2560 is a micro controller board based on the ATmega2560. Most of the input and output data are processed in this micro controller board. All sonar sensors, vibration motors and the Bluetooth module are connected to this micro controller. Following figure 3Illustrates how does this micro controller process inputs and generate appropriate output to the visually impaired user.

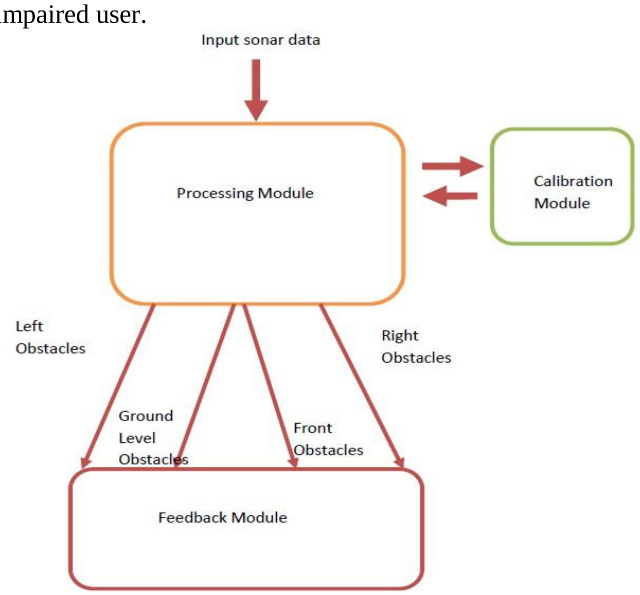

Fig. 3.Processing Module.

C. Feedback Module.

Feedback generation module is used to sense the obstacles for the visually impaired user and produce vibration feedback. To generate vibration feedback, the system uses vibration motors which are used in mobile phones. Sensing module measures distance to a particular obstacle and afterwards it gives inputs to the processing module. This module calculates and generates vibration feed back to the user. To generate vibration feedback five vibration motors have been used.
Three motors are mounted toa wearable belt in three different locations and two vibration motors for two wrist-bands. These vibration motors generate appropriate vibration feedbacks according to the distance. If an object is close for a collision, more powerful vibration feedback will be generated. In the vibration belt mid vibration is to identify front obstacles to the user. Other two vibrations in the belt are to identify drop offs and stair like obstacles. Other two wristband vibrations are to be worn on hands. Left side wristband is to notify about obstacles on the left hand side of the user and right side wrist band is tonotify about the obstacles on the left side of the user. All of these vibration motors change the intensity of vibrations matched to the distance to collide. Figure 4 illustrates how the vibration module generates feedback according to the control signals coming from processing module.

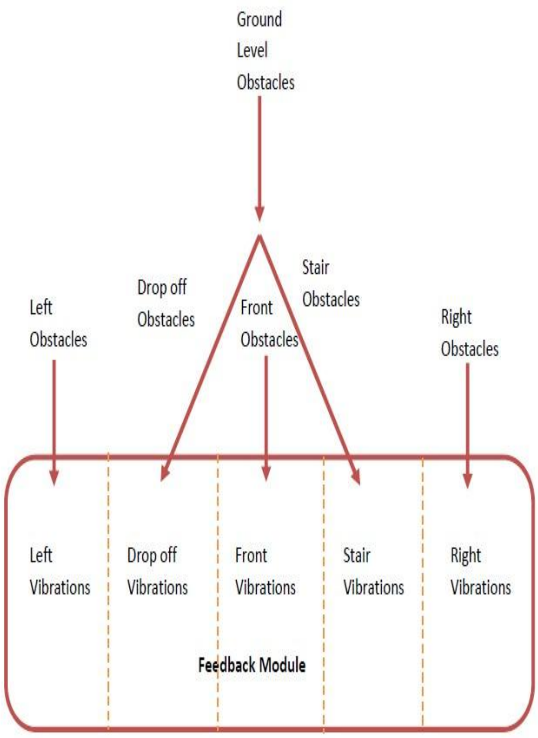

Fig. 4.Feedback module overview.

V. IMPLEMENTATION

A. Sensing Module

The implementation of the sensing module was based on four SRF05 ultrasonic ping sensors. Each sensor has the ability to emit sonar waves within 4m range. These sensors have mounted in four different locations of a wearable belt and each sensor can measure the time of flight of the emitted sonar wave. Figure 5 illustrates how this sensing module is implemented in the wearable belt does.

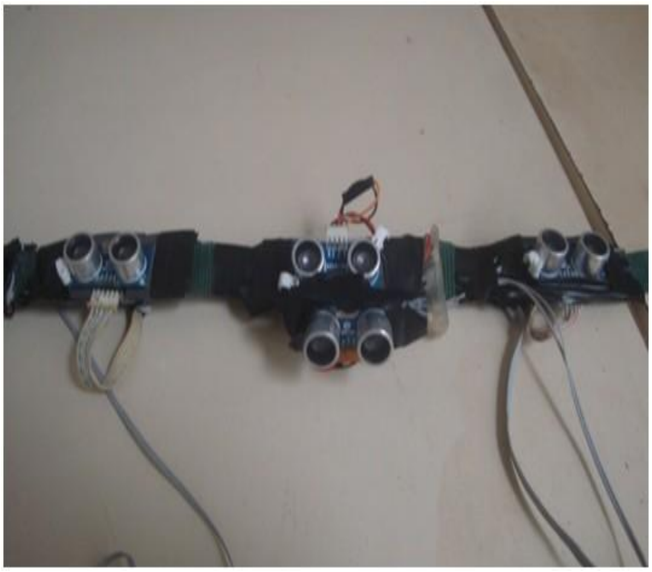

Fig. 5.Implementation of Sensing Module.

B. Sensing Module

Processing module gets the distance data from the sensing module. It processes all distance data and identifies what kind of obstacles are located ahead the user. To process inputs and generate outputs this research uses arduino mega2560 board. This processing module processes input sonar signals and generates relevant commands to produce feedback through feedback module which generates appropriate levels of vibrations. A system adaptation is also processed using this signal processing module which generates calibrations device inputs.

1) Calibration: First of all the wearable belt have to be adjusted according to a particular user. To do this, processing module takes inputs from calibration module and calibrates system according to user. Processing module takes some parameters from calibration module such as directed distance to ground level from the ground level sensor, user’s minimum and maximum vibration sensitivity levels, minimum and maximum obstacle sensing range for the user and maximum drop off size which can get the user move safely.
2) Sonar data processing: According to calibration parameters and each sonar sensor’s distance readings, processing module identifies obstacles. These obstacles are mainly classified into five groups; which are drop offs, stairs, front side, left side obstacles and right side obstacles. When a sudden change happens with the distance, the ground level sonar sensor identifies whether it is a drop off or a stair. Front side, left side and right side obstacle classification occur according to the user’s preferred distance parameters (side parameters).
3) Feedback: The feedback generation module is actively coupled with the processing module while the obstacle classification happens. After an obstacle is identified and classified, vibration feedback commandwill be provided to vibration module with relevant information. A relevant vibration motor will be activated with the relevant vibration intensity. Processing module generates vibration patterns according to obstacle classification. From the vibration pattern user gets a proper idea what kind of obstacle is located ahead.

C. Feedback Module

Feedback module produces vibration feedback to the user. From these vibration feedbacks user can get an idea about obstacle’s behavior and accordingly obstacles can be avoided. Feedback module hasfive coin vibration motors. These vibration motors are mounted to a separate belt and two wrist bands. This belt can be worn some place on human body such as thigh, chest and abdomen. The vibration belt has three vibration motors. These three vibration motors are used to inform about three types of obstacles suchas stairs, drop- offs, and front obstacles. To inform about left obstacles and right obstacles two wristbands with vibrations are used. User can get obstacle information further more by feeling and understanding different vibration patterns generated by all the motors. For an example if a wall is located in front of the user front, left and right vibration motors will increase their vibration intensity. From the pattern user can identify that there is a wall ahead. Figure 6-left illustrate how the motors can plugged to the main device easily. Vibration motor which is used to generate vibration feedback is shown by figure 6-right.

Fig. 6.Left - Vibration devices and the wearable belt, Right Coin vibration motor

D. Calibration Module

Calibration module calibrates the wearable device according to user’s perspective and preferences. User can adapt this wearable device by using a mobile device which has Bluetooth communication. This research uses android smart phone as the calibration tool. The wearable device is plugged into a Bluetooth module. The approach uses TTL Bluetooth module to communicate with a smart device. A mobile application has been developed based on android platform and which can be used to send calibration parameters to wearable device. This application can be used to personalize the system according to user’s preferences with the help of a 3rd party. Figure 7 shows a screen shot of the android application which is used for calibration purposes in this research.

Fig. 7. A Screen shot of android calibration application.

VI. EVALUATION

The evaluation process continued in an indoor environment which was previously adjusted and which was not seen by the participants before. The results of the evaluation were based on the observations during the evaluation and the user reviews of the system after the evaluation. The results have direct implications on human everyday navigation and guidance for visual impaired people.

These tests were carried out on 10 users; two of them were totally blind and they have experience in walking with a white cane, and rest of the eight users (5 male users 3 female users)have normal vision in this study but those participants were blind folded. All participants had normal hearing abilities and they did not have any other disabilities.

Several evaluation tests were conducted to verify the different features of the approach. The tests were carried out based on the learning methodology. The indoor navigation environment included a room which had different kinds of obstacles such as tables, chairs, walls and a corridor which was also included different kinds of static obstacles and moving people. Also there was a staircase included in the indoor environment to detect stairs and drop-offs. User evaluation for totally blind users is shown in figure 8 and drop off identification of a blind fold user is shown in figure 9.Before carrying out the evaluation tests the users was required to adapt the system. A third party person involved in this task and calibrated the system according to the user preferences using the calibration console. Participants were not aware of the environment and before the evaluation test began visually impaired users and blind fold participants were positions at a starting point by a third party person. User was guided through the environment by an outsider. While the user navigates through the environment, user reactions to each obstacle was observed and noted in the evaluation form. The time taken by each user to complete was also noted for further analysis. To evaluate how the familiarizationaffected this system, subjects were asked to move in the same environment 3 times and measured the completion time taken by each user at each attempt separately. After completing the evaluation tests with the wearable system, it was removed from the user and then user was given a white cane. To compare the system with the white cane same users traveled through the same environment with a white cane. By measuring the time taken to complete and the getting the number of confusions the system and the white cane solutions were compared.

Fig. 8.Evaluation process for visually impaired users.

Fig. 9. User evaluation for a blind fold user – drop off identification.

A. Results

The evaluation results of this research were taken to do analysis in several areas. To analyze the familiarization of this wearable device, time taken by the user to complete a given path is measured for all 3 attempts. Figure 10 graph refers to data set of the time taken in all 3 attempts by each of the user. In here user 9 and user 10 were visually impaired users. This graph gives the graphical view of how does user's familiarization to the device was affected to their mobility.

This research targeted to evaluate user reactions for multiple Vibration feedback patterns and how a user does reacts to avoid identified obstacles. For all three attempts obstacle detections are categorized into areas which were pre-identified as per the obstacle classification by the system. the obstacle categories have been identified as left side obstacles, right side obstacles, frontal obstacles , drop offs, stairs, opened doors and dynamic obstacles. If the user was successfully avoided the obstacle it was counted as an obstacle detection. When user got confused or if he/she failed to take immediate actions for the vibration feedback, then it counted as a confused situation.To analyses more about these identifications and confusions, user's obstacle identifications and confusions calculated as a percentage. For a single attempt there were 5 left side obstacles ,4 right side obstacles, 3 drop-offs, 4 stairs , 2 walls, 2 open doors , 2 front obstacles and 3 moving obstacles mounted to the environment. Figure 11 analyze the user obstacle identification rate as an average for all users for all3 attempts and Figure 12 analyzed the user confusions.

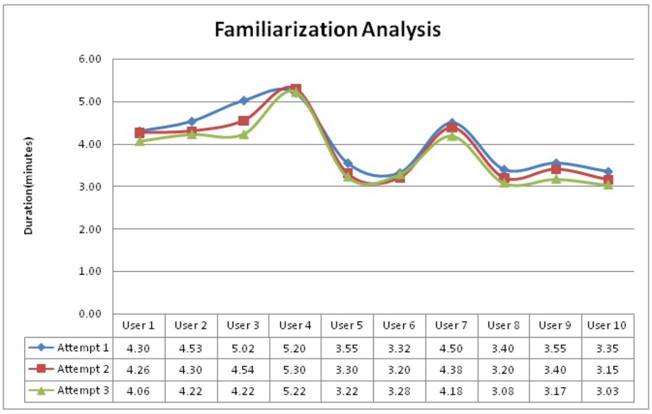

Fig. 10.Familiarization analysis.

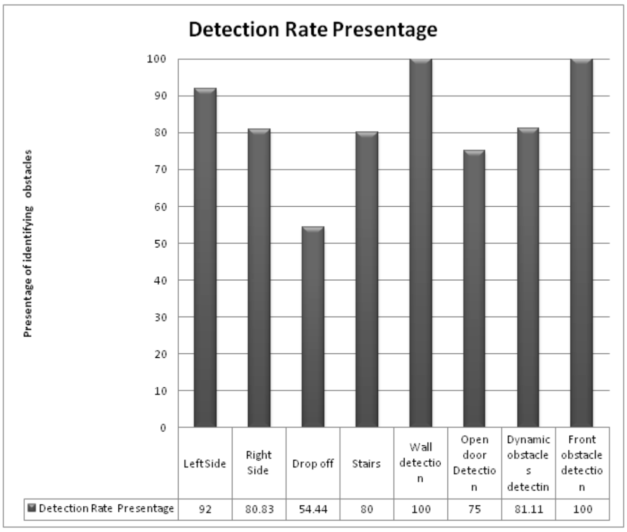

Fig. 11.Obstacle identification analysis.

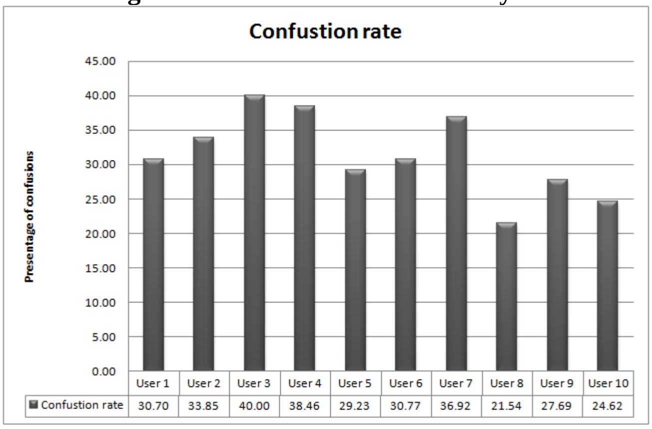

Fig. 12.User confusion analysis.

Comparing effectiveness of white cane and the wearable system was also an evaluation task of this research. Average time taken for all 3 attempts calculated for a user and time taken to travel using white cane also measured for the same environment. Figure 13 chart includes those gathered compared information for all users. Authors of rejected papers may revise and resubmit them to the journal again.

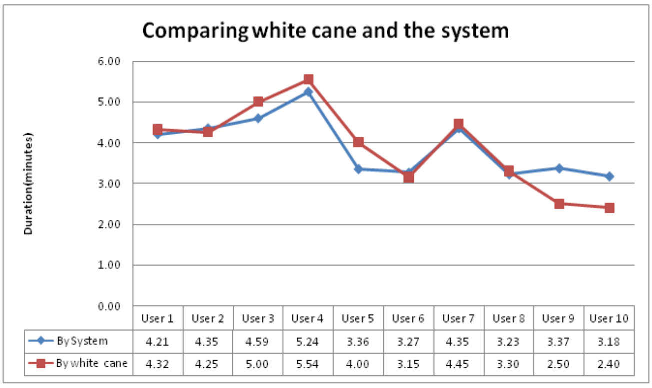

Fig. 13.Comparative analysis.

Evaluation of increasing user sensitivity by calibrating the system according to the user's necessity is done through a user review. During the training period the first user had to use the system without calibrating. Then the system calibrated according to the user's requests. When user finished his first attempt several questions asked from each user about how do these functions affected to their mobility improvement. Figure14 illustrate how does these calibration functions are effect to increase the sense of obstacles.

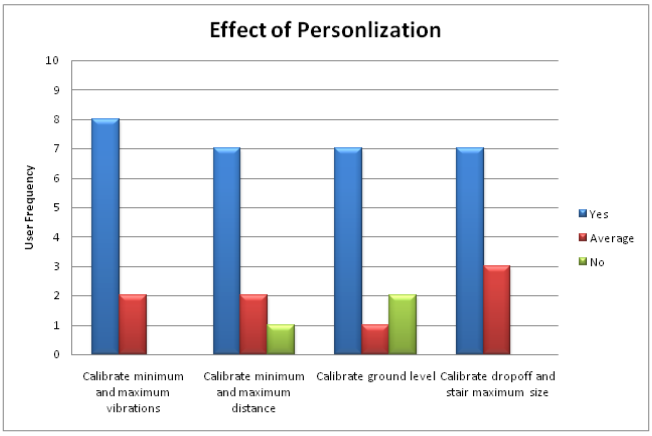

Fig. **14. Effect of personalize** for obstacle avoidance.

A. Analysis and Interpretation

The analysis of the evaluation phase will be carried out according to the main 3 dataset gathered during the evaluation process. As per the figure 10, the completion time taken by most of the users was decreased when the number of attempts they have taken increase. Some of the users took more time in their 2nd attempt than the 1st attempt but the time taken to complete the 3rd attempt was always less than the 1st attempt. Especially when focusing to the data gathered for visually impaired users in figure 10, the 2nd attempt and the3rd attempt always taken less time than its previous attempt. Therefore it is clear that the improvement in mobility by using this system is proportional to the number of times it used. This justifies that in order to use the system for the mobilityimprovements first user should have the proper training with the system. When considering figure 11 it can give an idea of average obstacles detection rate for users. According to this graph left side obstacles detection was about 92% and right side obstacles detection was about

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80%. When it comes to front obstacles detection it gave 100% obstacle detection rate. From these observations it can measure how does the user's sensitivity of identify obstacles ensue according to the orientations of the obstacle. When comes to drop offs and stairs, identifications of drop-offs was very low comparing to other obstacle detections. Many users have complained about drop-offs detections as they could not sense drop-offs until it is closer to the user. Due to this reason drop off identifications was laying in low average rates for users. Stairs detections were taken around 80%. This concludes that the system can identify stairs with a reasonable accuracy. Users could identify walls with 100% accuracy. This observation shows that the wearable obstacle detection system can identify walls without any confusion. Opened door detection rate was also given reasonable accuracy rate which was around 75%. User identifications of moving obstacles were given around 81%. One of the interesting observations which have been found out during the evaluation phase is that the user can identify moving obstacle's direction from this device's vibration pattern. When there is more than one obstacle around the user, he/she got confused in reacting for the multiple vibration feedbacks. This situation increased the number of confusions. However when considering the figure 12 it showed that the number of confusions rate is varying from 18% - 34% range. According to figure 13 the time taken by the users to travel through the environment using the system was lesser than the time taken with the white cane. 4 users walked fast by using white cane but among these 4, two were visually impaired people who are well experienced in using white cane. Therefore this research can give higher impact on the novel user's mobility improvements than white cane. During the evaluation phase user had a clear idea about how this system gives vibration feedback before calibrations and after calibrations. The figure 14 shows that many users strongly agreed those calibration functions had helped them on feedback senses. According to the user comments given at the interview after the evaluation process, it is better if the user gets a full training before they start to use it. They have highly appreciated the calibration console which used to personalize the system according to the user. The system should be developed in order to detect drop-offs when it appears at least few feet before the user. According to the visually impaired users this wearable system has a higher accuracy rate and user friendly compared to the white cane. Visually impaired users showed a higher response to the vibration feedback than blindfold users. However when the people who are visually impaired use the white cane, other people around them get to know that the person is visually impaired by observing the white cane. So during the interview they questioned about the social awareness they get from the outside if they use this system instead of white cane.

VII. CONCLUSION

The challenge of this research was to classify obstacles in a certain level and inform it to the user with a relevant feedback. To meet this challenge, in the design phase this study introduced four modules as Sensing module, Signal processing module, Feedback module and Calibrations module. The challenge behind sensing module was to sense a 3D environment which has obstacles like stairs and drop offs. From the design architecture this wearable device can sense ground level obstacles. This system supports a user to identify frontal obstacles which are occurred in user's navigation path. To warn the user about the obstacles, this system uses several vibration patterns. Another challenge occurred during this research was to adapt this system according to the user's perspective. This study introduced a mobile application which can communicate with the device via Bluetooth. From this calibration application a user can personalize the system according his/her perspective with a third party help.

According the experimental result of this study we can conclude that to get a higher accuracy the system user requires a proper training before the actual usage. Average obstacle detections rates can be listed as; left side detection rate 92%, right side detection rate 80.93%, front detection rate 100%, stair detection rate 80%, drop off detection rate 54.44%, dynamic obstacle detection rate 81.11%, wall detection rate is 100% and the open door detection rate is 75%. Drop off identification rate was low comparing to other obstacle detections due to the delay feedback to the user. Users confusion rate was varied from 18% - 34% range.

The system compared with the white cane by using the same environment and found out that the novel users travelled faster with the system than with the white cane. However well experienced white cane users completed the given path more quickly using white cane than using the system. From the personalization analysis extracted that the user's mobility has been improved when they calibrate the system according to their perspective. So it is recommended doing a personalized approach for wearable obstacle detection system. This solution is hand free personalized wearable obstacle detection system which is focused on improving the mobility of visually impaired users. However there are some limitations of using this system. This wearable device is not suitable to be used by multiple users who travel through the same environment. The reason behind this is that the sonar reflections may interfere with each device's sensors. There are some power consumption issues with this wearable device. From a single battery this device can perform only for less than one hour. These issues should be addressed in order to implement more reliable obstacle detection system. When doing the experimental study with the visually impaired people their comments were really encouraged.

According to their review this system is very useful to avoid obstacles when it compared with white cane. However they had a doubt that whether these devices can make social awareness for them. So it is not recommend removing the white cane completely from visually impaired users even they start using this system until this kind of devices can attain a social response to the visually impaired users.

VIII. FUTURE WORK

This wearable obstacle detection prototype proven that this can be used to improve mobility of visually impaired people. However to make this prototype usable in a real time system, lot of improvements can be planned as future works of this research. Reducing the power consumptions, Reduce the 3rd party help which used to adapt the system according to the user and investigate the possibility of self-adaptive wearable obstacle detection system, Use other available functions in calibration tool and investigate the possibility of complete path navigation and obstacle aware system are planned to be done in near future.

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