A Ground Plane Hazards Detection Tool for the Visually Impaired

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***Abstract*—The World Health Organization (WHO) reported an estimation of 36 million people who are legally blind this number is expected to be triple. One of the most important effects of vision loss is the loss of ability to travel around safely and independently. In general, the major problems encountered involve obstacles in the pathway and ground plane hazards. The ground plane hazards include the staircases, steps, potholes, pits, ramps, and drainage. Over the years, most of the existing smart devices focus more on the obstacle detection in the surroundings rather than the ground plane hazards which can turn out to be dangerous for the visually impaired. Thus, this project specifically focuses on the development of a smart detection tool for alerting the visually impaired on ground plane hazards. This paper discusses the prototype which is able to detect ground plane hazards like staircases, ramps, drainage and potholes. A real time detection test was conducted and the results proved that the prototype performs up to the expectation in real time.**

***Index Terms*—visual impairment, ground plane hazards, ultrasonic, detection, navigation, obstacles**

I. INTRODUCTION

According to the World Health Organization (WHO), an estimation of 253 million people lives with vision impairment, at which 36 million of them are blind [1]. Besides that, WHO estimated that the number of people with vision impairment could become triple due to the growth and ageing of the population. This may also indicate the increase in the need of assistive devices to aid in daily navigation and orientation.

In fact, domestic space is a complex environment filled with various obstacles in the surroundings: right, left, top and bottom. The congestion of such obstacles can cause problems even for any normal sighted people. The decision making of the visually impaired is often supported by the external assistance provided by white canes, trained guide dogs, human companion or smart electronic devices. Existing devices can detect and recognize objects above the ground. However, there are some unavoidable and undetectable ground plane hazards caused by drainage, potholes, ramps or staircases. Therefore, our interest focuses on the development of a smart solution for ground plane obstacle detection. We developed an evolutionary prototype which utilizes low computational cost, light weight and compact single rotatable ultrasonic sensor, designed in to the form of a wearable to detect ramps, staircases, potholes and drainage and alert the visually impaired about the obstacles in the ground plane.

II. BACKGROUND

A. Challenges Faced by the Visually Impaired

Vision loss affects many aspects of the life of visually impaired people. One of the most important effects is the ability to travel around safely and independently. According to a review among 31 selected studies, in the daily living activities, the visually impaired persons are 1.7 times more likely to have a fall and 1.9 times more likely to have multiple falls as compared to the sighted people [2]. Also, the chances of getting a hip fracture are between 1.3 and 1.9 times greater for those with visual impairment.

The problems related to mobility of visually impaired are the obstacles and ground plane hazards such as staircases, potholes, pits, ramps, and drainage.

Staircases are one of the most common artificial structures in daily environment to provide multilevel reaching possibilities [3]. However, staircases are also one of the most dangerous obstacles. Descending stairs are the most dangerous hazards for visually impaired especially those who use rollator or wheelchair [4]. Stacey reported a tragedy where a blind, wheelchair-bound teenager broke her neck and died after falling down from the stairs [5]. Through this heart-breaking incident, it is clear that the staircases are a serious hazard that requires higher attention especially for the visually impaired persons.

The most dangerous hazards faced by the visually impaired when they go out of their house is the uncovered drainage or ditches [6]. The drainage or ditches are very common which often exist between the streets and pavements. Another common issue is the improper installation of the tactile paving on the streets. There are many cases where the tactile paving leads the visually impaired right to the obstacles such as trees, bollards and ditches. The reason behind this issue is the

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workers do not have sufficient knowledge on tactile paving installation. Besides that, one of the blind people fell into a pit that was dug by the construction worker and the shattered the jaw in [6]. Another accident occurred when a visually impaired was on the way to the class with her friend. Suddenly, the friend disappeared because she fell into a deep ditch and was in pain. Blind people feel stressful to go out as they always come back with bruises on the bodies. From [6], it is clear that the ground plane condition has to be detected and alerted, otherwise it will turn into ground plane hazards. They have to be taken into serious consideration for improving the mobility of visually impaired people.

Another serious accident that occurs frequently is the fall of visually impaired people into the train platform. Recently, a visually impaired man fell into the train platform and broke his leg [7]. The man was saved just one minute before the train arrival. Moreover, Aoki reported that the total number of train platform falls in Tokyo increases from 2442 cases in 2009 to 3673 cases in 2014 [8]. This issue could be resolved if there is a safety barrier being installed. However, the huge cost of installation is an issue. Thus, if the visually impaired people have an assistive device that can help detecting the train platforms or holes in front of them before they fall into it, it would reduce the chances of fall accident from happening. Moreover, uncovered manholes and drains are virtual death traps in most of the streets in Malaysian cities. In 2016, a student fell into an uncovered manhole and suffered the loss of his kidney [9].

B. Ultrasonic Sensors Based Assistive Devices

There are various assistive devices made to help improving the lives of the visually impaired through obstacle detection, staircases and steps detection, pothole detection, ramp and drainage detection.

1) Obstacle detection

The locomotion assistive devices with infrared and ultrasonic sensors were suggested in [10]. They are easier to use when compared to the laser devices, because of their wide angle magnitude [10]. The tactile vibration feedback is preferable by the beginners as it is direct and easier to be understand but audible feedback become preferable if trained as it is more precise. The evaluation suggested that both tactile and audio interfaces need a good spatial representation and proprioception to scan for the obstacles in the environment. Also, this would be difficult for the people who were born blind as they do not have the spatial representation abilities [10].

Figure 1. Ultracane (Left) and Miniguide (Right) [11]

Roentgen studied the performance of Ultracane and the Miniguide (Fig. 1), evaluated them based on several criteria such as changes in the travel speed, Percentage Preferred Walking Speed (PPWS), type and number of mobility incidents made [11]. The results found them reduced the walking speed of the visually impaired, but managed to reduce the total number of the indoor mobility incidents. The users were not very satisfied with the weight and safety aspects of the devices.

Figure 2. MobiFree Cane [12]

A set of devices consisting of the MobiFree Cane, Sunglasses and Echo was developed in [12]. The concept is to create a network that links all the possible mobility aids to work together. The MobiFree Cane is an improved long cane to detect the holes and drop-offs at the floor-level (Fig. 2). The MobiFree Sunglasses and MobiFree Echo are presented in the form of conceptual design. The MobiFree Cane is equipped with ultrasonic sensors to keep track of the distance from the cane to the ground and provide feedback to the user through vibration. According to the field test results, the MobiFree Cane was able to detect drop-offs and holes for one step ahead of the user. However, the users complained that the cane is overweight.

Figure 3. Ultrasonic spectacular & waist belt [13]

On the other hand, Bhatlawande proposed an electronic navigation system for detecting obstacles within 5 meters range in front, left and right directions [13]. The system is made up of a pair of spectacles and a waist-belt (Fig. 3). These two devices are equipped with five ultrasonic sensor pairs. The system uses ultrasonic sensors to measure the distance from the obstacles in all direction. This is a basic obstacle detection system and it is unable to detect the ground level obstacles.

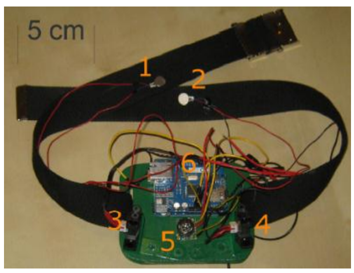

Figure 4. Hybrid Electronic Travel Aid [14]

A hybrid electronic travel aid, waist belt with infrared and ultrasonic sensors with vibration motors (Fig. 4) was developed in [14]. The device is equipped with a low-pass filter to smooth the output signals from the sensors. Users are notified about the obstacles through vibrating motors. The performance was unknown as there was no testing result being published.

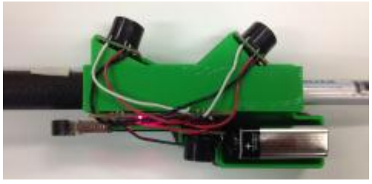

Figure 5. ioCane [15]

Leduc-Mills developed an attachable ioCane system for obstacle detection with three Maxbotic LV series ultrasonic sensors, and a mobile phone with a specifically designed Android App (Fig. 5). The ioCane system uses the mobile phone to provide feedback for the users through chimes and vibrations [15]. The testing results showed an improvement in the obstacle avoidance for ioCane when compared to normal white cane. The ioCane system is unable to detect the ground state for the visually impaired.

Figure 6. Walk Safe Cane (WSC) [16]

Walk Safe Cane (WSC) shown in Fig. 6 is a navigation aid that helps the visually impaired to detect obstacles in front of them with the distance and the velocity measurement [16]. An alarming system with three buzzers attached to a baby bib is included for providing alert about the incoming obstacles detected by the WSC. However, the researcher did not present any experimental result data and stated that further trials will be conducted.

Ahlmark developed two prototype of navigation aids, namely Virtual White Cane and the LaserNavigator that can convey the spatial information non-visually by using a haptic interface [14]. The researcher emphasizes that the haptic interface can provide interaction which is very similar to white cane.

Figure 7. The Virtual White Cane installed on the MICA (Mobile Internet Connected Assistant) Wheelchair [17]

The virtual white cane is an additional device added to the existing autonomous powered wheelchair, MICA (Fig. 7). The virtual white cane uses the laptop to collect the range information from the rangefinder and then builds a 3-D model and presents to the visually impaired through a haptic interface. The participants complained that they were unable to estimate the position of the obstacles that they felt.

Figure 8. The LaserNavigator [17]

LaserNavigator is a complement to the standard white cane that allows a blind user to discover his/her surroundings when necessary [17]. LaserNavigator is made up of a laser rangefinder, an ultrasonic sensor, a loudspeaker, and a microcontroller (Fig. 8). The LaserNavigator allows the user to vary the length of the virtual white cane by moving the device towards or away from the body. For haptic feedback, a small loudspeaker is used. However, users complained about the weight and complexity in coupling it with white cane.

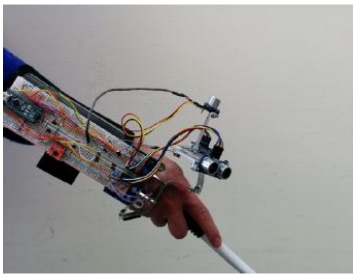

Figure 9. Smart Glove [15]

A smart glove equipped with rangefinders to explore the surroundings and provide vitro-tactile feedback of obstacles working with a white cane is developed (Fig. 9) in [15]. However, the comfort and weight need to be further improved by an accurate ergonomic design of the glove.

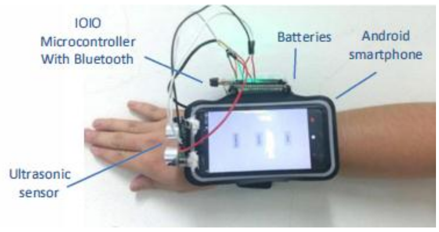

Figure 10. A Wrist-mounted Wearable Device [19]

Fig. 10 shows a wrist-mounted wearable device for helping visually impaired to avoid obstacles and move around more efficiently with only a white cane [19]. The ultrasonic sensor receives commands from the smartphone and sends the distance data back to the phone via a Bluetooth connection. This system has two detection modes, obstacles on ground level and above ground level. The device was tested and showed a satisfactory result on its usability and learning time. However, the weight and comfort is an issue when it is used continuously.

2) Staircases and steps detection

Many assistive technologies have been introduced for aiding and improving the orientation and mobility of the visually impaired persons (VIPs). Among all the potential hazards faced by the VIPs, stairs or steps are one of the most common structures which exist in the urban environment and living accommodations. Ishiwata, Sekiguchi et al. (2013) proposed a step detection system to support the mobility of the visually impaired. The system is made up of a sensor unit that is attached to the user's chest and a PC with battery installed in a backpack.

Figure 11. A Step Detection System [20]

Fig. 11 shows the step detection system that uses a small laser range sensor to obtain the distance information in the vertical cross-sectional plane in front. The detection system analyzes the segment and provide information on the existence of step to the users by voice and beep sound [20]. The device showed a great performance of over 95% for both upstairs and downstairs. However, the system is not tested in an outdoor environment. For this system, the weight of the sensor unit is about 0.5 kg and the backpack is around 3.4 kg. This is an issue as the device is heavy and might affect the mobility of the user. Besides, the power supply for the device and the duration it can be used is not indicated.

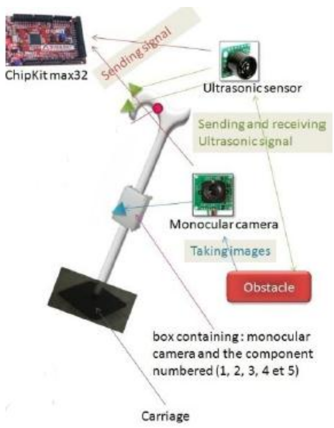

Figure 12. Electronic Cane [21]

Besides, Bouhamed built an electronic cane with two ultrasonic sensors (stair case detection and ground obstacle detection) and a monocular camera for obstacle detection (Fig. 12) [21]. The staircase detection system keeps track on the changing reading of the ultrasonic sensor from the ground to identify the terrain in front such as floor, ascending or descending stair cases. The experimental results showed that the detection rate of stair case is estimated to be 89.8%.

3) Pothole detection

With the advancements in today technology, assistive technologies such as Electronic Travel Aids (ETAs) have been widely introduced for helping the navigation of the blind by interpreting the information about the surrounding environment and feedback the information to the visually impaired persons in the form that can be understand by them. However, throughout the developed assistive navigation devices, there is still lack of devices that help the visually impaired persons to detect the ground floor state, such as the potholes on their way, especially during night time when the surrounding is dark.

Saraf developed an IVR based intelligent guidance stick for obstacle and pothole detection. The stick consists of three ultrasonic sensors pointed in different direction to detect the range of incoming obstacle and provide voice based instruction when the obstacle is within the safe zone [22]. The intelligent guidance stick is designed for only one ground state detection, pothole and this is not enough to guide the visually impaired persons to navigate around safely.

Figure 13. Smart white cane [23]

Sheth developed a Smart White Cane (Fig. 13) for obstacle detection (low lying, knee level and above wrist level) and detection of potholes, pits, downfalls, and ascending or descending staircase [23]. The system uses four ultrasonic sensors for obstacle and ground floor state detection, with sound and vibration feedback. The experimental results were not presented, thus the performance of the device in detecting the ground state is an unknown.

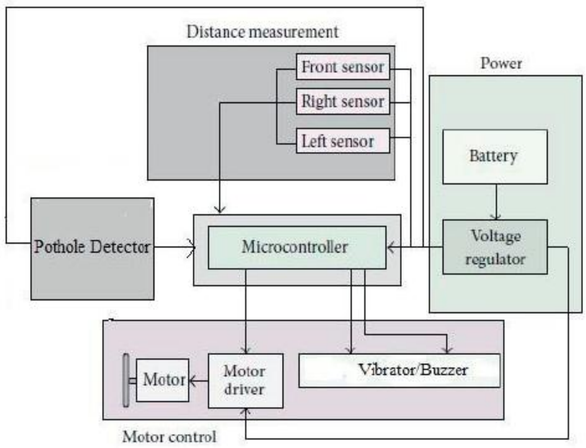

Figure 14. Block diagram of the blind man stick [24]

Parikh developed a blind man stick to detect obstacles and potholes in the path (Fig. 14). The obstacle detection system uses three ultrasonic sensors for front, left and right detection [24]. The analogue output signal from the sensors will be entered into the microcontroller to calculate the distance from the obstacle, sound the buzzer and activate the vibrator to provide alert when necessary. For the pothole detection, two techniques were suggested. Firstly, pothole can be detected by using the ultrasonic sensor by measurement of the distance between the stick and the ground. Secondly, the pothole can be detected by an accelerometer attached to a stone that will be hanging from a thread on the stick. The main drawback is the stick needs to go into the pothole in order to detect it, this may cause unintended accident when the blind user could not response in time.

Figure 15. Simple jacket mobility aid [25]

Sourab proposed a jacket (Fig. 15) with five ultrasonic sensors for detecting potholes or stairs, obstacles at head level, front, left and right sides of the user [25]. The user is notified by voice messages through headphones when there is a hazard.

4) Ramp and drainage detection

Herghelegiu proposed an algorithm for ground plane detection to aid the visually impaired in navigating around freely and safely.

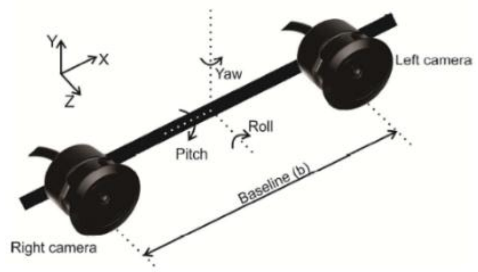

Figure 16. Stereo camera rig prototype [26]

The prototype uses a stereo camera rig to be worn by the users (Fig. 16). In the algorithm, the consideration of the orientation of the camera, namely its pitch and roll. This consideration is important to calibrate the variation in the captured images when moving. The proposed algorithm used v-disparity maps to represent the ground plane by a line or a line segment [26]. Then, the algorithm keeps track of the line segment of the detected ground plane in the consecutive frame in order to validate the detected ground plane. The limitation of the algorithm is encountered when the user faces an uphill, downhill or when the camera is aligned with the horizontal axis. Also, the performance of the algorithm in real time scenarios was yet to be determined as the testing was only performed by using the synthetic data generated by virtual environment framework.

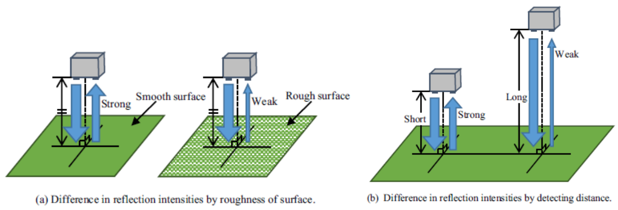

Figure 17. Concept of the road surface condition distinction method [27]

Nakashima proposed a method to identify the road surface condition by using the ultrasonic sensor. The recognition of the surface conditions is achieved by using the reflected intensities obtained by the ultrasonic sensor [27]. In the paper, Nakashima discussed about the improvement of their developed method on the detection of additional road conditions such as puddle, asphalt, soil and lawn. The proposed method is able to identify the road surface conditions by using the defined threshold (Fig. 17) which is determined through experimental data collected based on the reflected intensities of different road conditions. The effectiveness was confirmed based on the experimental testing. However, the proposed method is yet to be applied on the actual assistive devices for the visually impaired. Another issue would be the effect of the pointing angle of the ultrasonic sensors on the outcome of the detection as the collected data was based on the incident angle of 90˚.

III. Research Problem

Several design considerations have been taken into account for an efficient and economical smart solution to enhance the orientation and mobility of the visually impaired.

For the design of the smart technology, the first consideration is whether it is more economical to create the device with range-based sensors or vision-based sensors. By addressing this, the proposed prototype decided to use the range sensors as it offers a better solution for tackling the difficulties in ground plane conditions checking as compared to the vision sensors in term of their cost, performance and invasiveness. Invasiveness is one of the reasons that affect the acceptance of existing visual substitution devices by the visually impaired.

Secondly, the consideration is whether a smart solution offers supplementary, equal or better range and performance than traditional guidance sources like white cane or guide dog. By utilizing the ranging sensor, the proposed design solution will offer a better range as compared to the traditional guidance sources. Also, the proposed design solution is a good mobility aid as it is able to tackle more ground plane conditions safely which could not be achieved by using only the traditional guidance sources.

Thirdly, the consideration includes whether a smart solution is unique among the existing smart technologies in the market. The proposed design solution has its novelty as it was designed after completing the literature and product surveys on existing smart technologies in the past decades.

Lastly, the consideration includes whether a smart solution will replace the traditional guidance sources and whether it a standalone or secondary guidance source to enhance the orientation and mobility. The proposed design solution will not replace the traditional guidance sources. Instead, it will be used with white cane as a secondary guidance source of orientation and mobility. The use of the proposed design solution together with traditional white cane enables an enhanced orientation and mobility for the visually impaired.

IV. Proposed Solution

A. Prototype Design

Based on the evaluation from literature review, the proposed design must include several considerations such as simplicity, reliability, economically and user-friendly. Thus, in the initial design, the proposed device was decided to be constructed in small form factor, as small as possible, low cost and can be easily adopted by the visually impaired. Fig. 19 shows the prototype of the proposed solution with green silicone strap

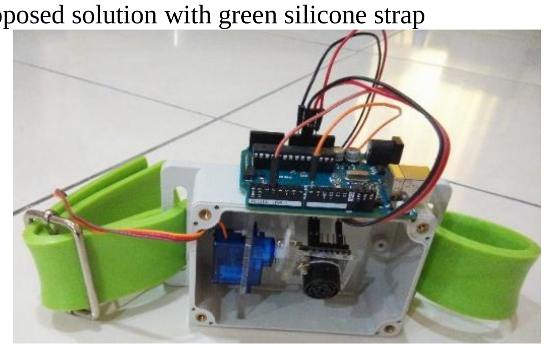

Figure 18. Completed prototype

B. Detection Algorithm

The overall ground plane hazard detection process starts by obtaining the two reference ultrasonic sensor range readings at two different pointing angles, 30 degrees and 45 degrees from horizontal axis as in Fig. 20. After that, the sensors continuously measure the distance values from the ground so that the system can keep track of the changes in the ground plane condition. During the operation, the detection is divided into two separate sections at which one responds for the increase in range reading, and the other responds for the decrease in range reading. When the sensor reads an increase in the range from the ground, the possible hazards encountered by the user include the descending staircase, descending ramp, drainage and pothole. As for the other group where the sensor reads a decrease in range reading, the possible hazards are ascending staircase and ascending ramp.

1) Ascending staircase and ramp detection

During the detection process, the sensor measures the distance to the ground at reference point one, θ_1 to ensure a safe ground plane condition with a constant distance, x_{R1} as shown in Fig. 19 and Fig. 20. The reference distance to ground, x_{R2} is measured at second reference point, θ_2.

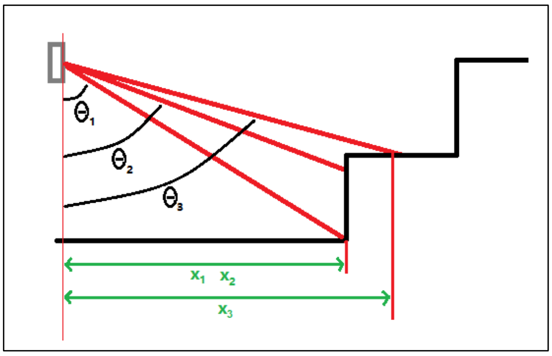

Figure 19. Detection algorithm for ascending staircase

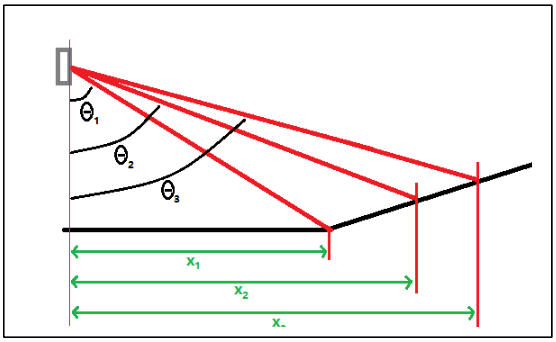

Figure 20. Detection algorithm for ascending ramp

When there is a decrease in distance at θ_1, the second sensor is rotated towards the second reference point, θ_2 to identify the changes in distance from the sensor. The distance, x_2 is calculated by using the θ_2.

$$x_2 = Measured\ Distance * \sin\theta_2$$

The verification between ascending staircase and ramp is identified based on the distance reading obtained from both positions, x_1 and x_2.

$$If\ (x_{R1} - x_1 < 50), \quad rampFlag = 1;$$

$$If\ (x_{R2} - x_2 > 200\ \ \&\&\ \ rampFlag == 1),\ upRampScenario = true;$$

$$If\ (x_{R2} - x_2 > 100\ \ \&\&\ \ rampFlag == 0),\ upStaircaseScenario = true;$$

The verification between ascending staircase and ramp begins with checking changes of the range reading at position one and then follows by the changes at position two. If the range reading at position one fulfil the condition of a ramp scenario, then the ramp flag will be marked. If the condition at the second position is fulfil, then it will be identified as an ascending ramp. On the other hand, if a ramp flag is not marked and the second condition at second position is fulfilled, then it will be identified as ascending staircase.

2) Descending staircase and ramp detection

Similarly, the detection process for descending staircase and ramp starts with obtaining the reference distance, x_{R1} and x_{R2} at the two consecutive reference point, θ_1 and θ_2 as shown in Fig. 21 and Fig. 22.

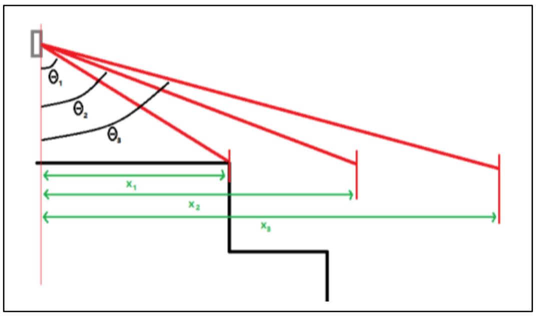

Figure 21. Detection Algorithm for Descending Staircase

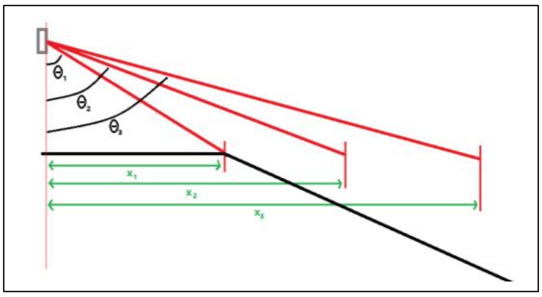

Figure 22. Detection Algorithm for Descending Ramp

When there is an increase in distance at θ_1, the sensor will be rotated towards the second reference point, θ_2 to measure the current distance reading. The distance, x_2 will be calculated by using the θ_2.

$$If\ (x_{R1} - x_1 < 150), \quad rampFlag = 1;$$

$$If\ (x_{R2} - x_2 < 800\ \ \&\&\ \ rampFlag == 1),\ downRampScenario = true;$$

$$If\ (x_{R2} - x_2 > x_{R2} - 100\ \ \&\&\ \ rampFlag == 0),\ downStaircaseScenario = true;$$

The identification between descending staircase and ramp are carried out by checking the range reading obtained from the sensor. If the readings fulfil the criteria for a descending ramp, then a ramp flag will be marked. However, if the ramp flag is unmarked, the possible hazard is descending staircase at which the range reading experienced a huge change from the reference.

3) Drainage and Potholes Detection

The detection for drainage and pothole also starts with the process of getting the reference distance, x_{R1} and x_{R2} at the two consecutive reference points, θ_1 and θ_2 as shown in Fig. 23.

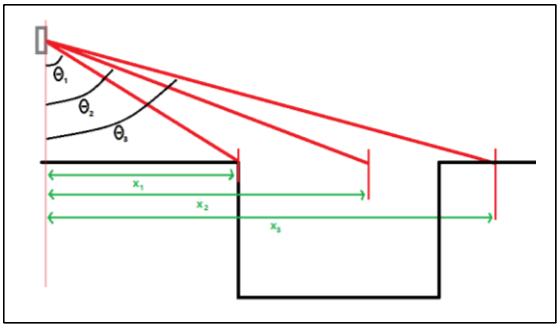

Figure 23. Detection algorithm for drainage and pothole

When there is an increase in distance at θ_1, the sensor is rotated to the second reference point, θ_2. The current reading will be used for verifying between descending staircase, ramp, drainage and pothole.

$$If\ (x_2 > x_{R2} - 50\ \ \&\&\ x_2 < x_{R2} + 50),\ drainagePotholeScenario = true;$$

When the condition for drainage and pothole is fulfilled, the sensor will be rotated back to the first reference point, θ_1 to obtain the reading for the verification between drainage and pothole.

C. Success Rate and Failure Rate of Detection

Success rate, S_R indicates the rate of successful detection and recognition of the hazards in front of the user. Failure rate indicates the false or wrong detection. When success rate adds up with the failure rate, it equals to 100%.

$$S_R = \frac{\sum D_S}{\sum D_T} \times 100\%$$

$$Failure\ Rate = 100\% - Success\ Rate$$

$\sum D_S$ denotes the total number of successful detection for the hazards.

$\sum D_T$ refers to the total number of detection that occurs.

False positive rate, F_P is known to be the false alarm, at which the detection indicates the existence of the hazards in front of the users, but actually it does not.

$$F_P = \frac{\sum D_{FP}}{\sum D_T} \times 100\%$$

$\sum D_{FP}$ denotes the total number of false positive detection that presence in the collected data sample.

$\sum D_T$ refers to the total number of detection that occur in the collected data sample.

False negative rate, F_N is the opposite of the false positive rate, at which the detection indicates the absence of the hazards in front of the users, but in fact it does.

$$F_N = \frac{\sum D_{FN}}{\sum D_T} \times 100\%$$

$\sum D_{FN}$ denotes the total number of false negative detection that presence in the collected data sample.

$\sum D_T$ refers to the total number of detection that occur in the collected data sample.

V. Testing with Various Scenarios

This section demonstrates the validations of the prototype on various possible hazards prior to running testing with the visually impaired in the field. According to the experiment conducted by Schellingerhout [28], the average walking speed of the visually impaired with traditional cane is 0.87 m/s. Thus, the mean walking speed used in this testing is between 0.80±0.1 m/s. The picture in Fig. 24 shows the blindfolded person doing testing in front of the ascending ramp.

For each experiment, the user started in front of the hazard at a distance of 1.5m and walked towards the hazard. The experiment was conducted under normal daylight condition. The pictures in Fig. 25 show where the experiment was carried out for each scenario. These locations were selected as they simulated the typical ground plane hazards encountered by the visually impaired in their daily activities.

VI. Results and Discussions

The experiment results for Phase 1 Testing are tabulated in Table I. and Table II. As shown in Table I, the average success rate for each ground plane hazard, is approximately 90%, which is deemed acceptable. However, we aim to achieve higher success rate in the following phases.

Table II presents the false positive and false negative rates of the detection during the testing. The results show that the highest mean false positive rate is 5% and the highest average false negative rate is 8.23%. This indicates that there was some false alarms or wrong detection during the testing but it was not frequent, thus it can be concluded that the proposed solution is usable for real time detection.

Figure 24. The Blindfolded Researcher Going Up a Ramp

(a) Ascending Staircase (b) Descending Staircase

(c) Ascending Ramp (d) Descending Ramp

(e) Drainage (f) Pothole

Figure 25. Various Possible Hazards Being Tested

TABLE I. RESULTS FOR PHASE 1 TESTING

Scenario	Ascending Staircase	Descending Staircase	Ascending Ramp	Descending Ramp	Drainage	Pothole
Experiment 1						
No. of Success Detection	18	19	16	15	14	15
No. of False Detection	2	1	4	0	2	2
Total No. of Detection	20	20	20	15	16	17
Success Rate	90%	95%	80%	100%	87.5%	88.2%
Experiment 2						
No. of Success Detection	18	17	19	14	15	14
No. of False Detection	2	3	1	1	1	3
Total No. of Detection	20	20	20	15	16	17
Success Rate	90%	85%	95%	93.33%	93.75%	82.35%
Experiment 3						
No. of Success Detection	18	18	18	14	15	16
No. of False Detection	2	2	2	1	1	1
Total No. of Detection	20	20	20	15	16	17
Success Rate	90%	90%	90%	93.33%	93.75%	94.12%
Experiment 4						
No. of Success Detection	19	18	19	14	15	15
No. of False Detection	1	2	1	1	1	2
Total No. of Detection	20	20	20	15	16	17
Success Rate	95%	90%	95%	93.33%	93.75%	88.2%
Experiment 5						
No. of Success Detection	18	20	19	13	14	15
No. of False Detection	2	0	1	2	2	2
Total No. of Detection	20	20	20	15	16	17
Success Rate	90%	100%	95%	86.67%	87.5%	88.2%
Average Success Rate	91%	92%	91%	93.33%	91.25%	88.21%
Standard Deviation	2.23%	5.70%	6.52%	4.71%	3.42%	4.16%

TABLE II. RESULTS FOR PHASE 1 FALSE POSITIVE AND NEGATIVE RATES

Experiment	Scenario	Ascending Staircase	Descending Staircase	Ascending Ramp	Descending Ramp	Drainage	Pothole
1	No. of False Positive Detection	0	0	1	0	1	1
	No. of False Negative Detection	2	1	3	0	1	1
	Total No. of Detection	20	20	20	15	16	17
	False Positive Rate	0%	0%	5%	0%	6.25%	5.88%
	False Negative Rate	10%	5%	15%	0%	6.25%	5.88%
2	No. of False Positive Detection	1	1	1	1	1	1
	No. of False Negative Detection	1	2	0	0	0	2
	Total No. of Detection	20	20	20	15	16	17
	False Positive Rate	5%	5%	5%	6.67%	6.25%	5.88%
	False Negative Rate	5%	10%	0%	0%	0%	11.76%
3	No. of False Positive Detection	1	1	0	0	1	1
	No. of False Negative Detection	1	1	2	1	0	0
	Total No. of Detection	20	20	20	15	16	17
	False Positive Rate	5%	5%	0%	0%	6.25%	5.88%
	False Negative Rate	5%	5%	10%	6.67%	0%	0%
4	No. of False Positive Detection	1	2	0	0	0	0
	No. of False Negative Detection	0	0	1	1	1	2
	Total No. of Detection	20	20	20	15	16	17
	False Positive Rate	5%	10%	0%	0%	0%	0%
	False Negative Rate	0%	0%	5%	6.67%	6.25%	11.76%
5	No. of False Positive Detection	2	0	0	0	0	0
	No. of False Negative Detection	0	0	1	2	2	2
	Total No. of Detection	20	20	20	15	16	17
	False Positive Rate	10%	0%	0%	0%	0%	0%
	False Negative Rate	0%	0%	5%	13.33%	12.5%	11.76%
Average False Positive Rate		5%	4%	2%	1.33%	3.75%	3.53%
Standard Deviation of False Positive Rate		3.54%	4.18%	2.74%	2.98%	3.42%	3.22%
Average False Negative Rate		4%	4%	7%	5.33%	5%	8.23%
Standard Deviation of False Negative Rate		4.18%	4.18%	5.70%	5.58%	5.23%	5.26%

VII. Conclusion and Future Works

In this paper, the detection of ground plane hazards is discussed and the experimental results with several possible hazards are included. Through this research work, we have successfully designed and developed a prototype for detecting ground plane hazards. The testing with blindfolded users was completed with the results proving that the prototype performs well for real time detection. For the future works, we expect to improve the success rate in real time detection to 95%. Once the detection algorithms are optimized with confidence, the testing with different scenarios for each hazard will be conducted with blind participants. Also, we will work on providing the cues via smartphone.

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