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Finger-Mounted Obstacle Detector for People with Visual Impairment

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***Abstract*—Mobility is the ability to move. People with visual impairment has limited mobility as they have limited vision to move safely without colliding against obstacles. This paper presents a wearable device using technology to help people with visual impairment to detect obstacles. The device uses an ultrasonic sensor to obtain real time information of distance between device and obstacles. This information is interpreted into an audio feedback which will alert or notify users the presence of obstacles in their path. The device is small enough to be worn on the finger and direction of detection can be changed by pointing the hand or finger elsewhere. Three experimental testing were conducted to evaluate the prototype. First experiment was to determine the detection rate on indoor and outdoor obstacles of different sizes and shapes in a controlled environment. Second experiment was to test the prototype with participants wearing blindfolds (no vision simulator) and walking in an indoor environment filled with real life obstacles. Third experiment was conducted with participants wearing low vision simulators walking in an outdoor environment. Results showed the prototype works better for people with low vision than no vision.**

***Index Terms*—assistive technology, obstacle detection, ultrasonic rangefinder, visual impaired**

I. INTRODUCTION

Mobility is the ability to move easily and safely from one location to another. Human beings are designed to be a mobile creature but not everyone is mobile. Disease, accident, and genetic can result in mobility limitation. One limitation, visual impairment, reduces the mobility of people who suffers from the impairment.

Assistive devices or tools are used to improve the mobility of people with visual impairment such as a cane, guide dog and human assistance. However, the existing tools have limitations. Sweeping or tapping of the cane on the ground helps people with visual impairment in detecting ground level obstacle but not obstacles that are above waist level such as tree branches and open windows. Guide dogs could be trained to stop when there is obstacle, but it requires more care and expenses to maintain the dogs. Human assistance is the best solution but is very impractical as it involves constant human supervision.

II. BACKGROUND

Numerous studies were conducted to improve the mobility of people with visual impairment by designing a device that can detect obstacles. Two common obstacle detection techniques used are vision-based and sensor-based. Vision-based obstacle detector obtains information through camera which can be mono-camera, stereo-camera or RGB-D camera [1]. In most vision-based applications, it requires a processor with high computational power to break down and obtain the desired information from the camera image which contains many information. There are many algorithms developed by researchers to do certain tasks but it has limited functionality in obtaining information on objects that are transparent and in dark environment.

Sensor-based method is usually straightforward as the sensors are designed to perform a specific task. Laser sensor has high precision and resolution which are commonly found in mobile robot navigation. The sensor, however, can be expensive and may not perform well in an environment exposed to strong sunlight. An ultrasonic sensor can measure distance of obstacles but it has lower accuracy when compared to laser. It has a wider range of detection but depending on usage, this characteristic can be a drawback when a precise detection of obstacle location is desired.

Some existing research works are ultrasonic-based obstacle detection which can be categorized into cane, robot and wearable. Smart canes are walking sticks used by people with visual impairment embedded with smart technology and are developed by several researchers [2]-[6]. The distinct differences of the developed prototypes are the amount of sensor implemented, the feedback system used for notification, length of the stick, and the field of detection.

Two ultrasonic sensors were implemented and were located at the bottom of the stick [2]. It detects ground level obstacle from left and right simultaneously. Haptic feedback was implemented on the handle of the cane. The prototype was designed to replace walking stick and is capable of detecting obstacle taller than 10cm. However, the maximum detectable height was not evaluated.

A similar prototype [3] was built with two ultrasonic sensors located at the bottom, haptic feedback but with an additional feature of audio feedback. Sets of sound are stored and will be played when obstacles are detected. It is designed to detect ground-level obstacle so people with

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visual impairment is still vulnerable to obstacle above waist.

A prototype designed in [4] attached one ultrasonic sensor near the handle of a cane. The sensor is carefully positioned so that it does not detect the cane while capable of detecting obstacle from waist to ground with no swinging motion. Audio feedback system was implemented and the message is relayed through an earphone. This, however, can lead to difficulty in hearing of surrounding sounds which may be potentially dangerous to people with visual impairment.

Taking a step further, ultrasonic sensors and GPS module [5] were implemented into the walking stick to provide both obstacle detection and navigation for people with visual impairment. Two sensors are positioned near the handle to detect left and right waist-level obstacle and one sensor at the bottom to detect obstacle in front of the user. Both audio and haptic feedbacks were implemented. The performance and usability of the prototype for both indoor and outdoor environments were not evaluated by the researchers.

An array of ultrasonic sensors, GPS module and GSM module were implemented in [6]. The GPS and GSM modules served to send coordinates of user to other people at times of emergency. Three sensors are positioned near the handle to detect left, front and right obstacle and two sensors at the bottom to detect terrain change. A moisture sensor was also implemented to detect presence of water on the ground. Presence of obstacle are notified using haptic feedback and changes in terrain are notified using audio feedback. However, the usability of the prototype with implementation of GPS, GSM, and moisture sensor is not evaluated.

A robot-based path guidance and obstacle detector was proposed in [7]. To use the robot, the user is required to attach a stick on the robot. When there is a path, the robot will move accordingly. But when there is no path, the robot will only detect obstacles. The usability of this prototype is unknown as no evaluation was made.

A different approach of using ultrasonic sensors for obstacle detection is to make it wearable. A wearable head-mounted obstacle detector developed in [8] uses headset to mount all the electronics and is powered using solar. The use of only solar resulted in limited usage of the prototype and headset as the feedback cue can be dangerous similar to the previous prototype [4] in which the hearing sense is limited.

Wrist-based obstacle detector [8] used incorporate ultrasonic sensor and smartphone altogether. Raw data coming from the sensor is processed by a microcontroller and is sent to a smartphone through Bluetooth. From the data, audio and haptic feedbacks are produced accordingly. Moving the hand or wrist allows the user more control in what they want to sense using the prototype such as ground or above ground level obstacles. Prolong usage of the prototype can be tiring because the smartphone is mounted on the wrist. Furthermore, due to the separation of the sensor and processing units, in the event one of the units failed to operate, the prototype is rendered useless.

A lightweight prototype called iSonar [10] was designed to be worn as a necklace and detects waist to head level obstacle. Audio and haptic feedbacks are implemented and are able to alert the user when power is low. Wearing the device around the neck can result in false detection during walking due to body movement.

Array of sensors built on glasses and belt was designed and developed in [11]. Two ultrasonic sensors are placed on the glasses and three sensors are positioned individually on the left, center and right of a belt. The sensor placement allows the detection of waist to head level obstacles. A flaw in this design is in its inability to detect ground level obstacle as no sensor is specifically placed to detect ground level obstacle. Usage of a cane together with the prototypes may give false detection due to the placement of sensor on the belt and this was not evaluated.

A ring-based obstacle detector was produced and sold which is called Live Braille [12]. It uses an ultrasonic sensor o detect obstacles. However, the product is not sold anymore and there is very little information regarding the usability of the device.

In summary, vision-based devices require high computational microprocessors which consume lots of power, resulting in overall large form factor due to power generating unit such as a battery or power adapter. Sonar sensor based devices require less computation and power. However, most of the prototypes were not evaluated for their performance and usability [5]-[7], [11], [12]. Some prototypes [4], [8] used headphones or earpiece to alert the user which is potentially dangerous. In addition, wearable detectors require careful positioning to reduce false detection due to swinging motion during walking [10] or incompatible usage with white cane [11]. A wearable detector can also be obstructive and heavy for long period of use [8], [9].

III. RESEARCH PROBLEM

People with visual impairment have trouble in moving safely on a path that has obstacles. This issue exposes people with visual impairment to dangerous situations such as colliding against overhead posts and this needs to be addressed to improve the mobility of people with visual impairment and reduce unwanted danger, accident and fatality.

Many research works aim to improve the life of people with visual impairment such as proposing, designing and developing obstacle detector. However, existing solutions have some limitations such as inability to use a cane in the event of technology failure, inability to use in indoor and outdoor environment, failure to address a lightweight solution for wearable device, failure to address safe use of technology, and lack of performance and usability evaluation.

There are several factors to consider when developing an obstacle detector for people with visual impairment. Firstly, what type of sensors are to be used for the detector? Secondly, is the prototype being designed as a replacement or supplementary device? Thirdly, will it be used to detect ground, waist and/or head level obstacles?

Fourthly, what form will it be; a cane, a robot or a wearable? Lastly, how well the developed prototype can detect an obstacle?

IV. PROPOSED SOLUTION

In this research, the proposed design is a wearable ultrasonic-based obstacle detector. It is used as a supplementary device and is not meant to replace the cane. As it is a wearable, the prototype design is small and lightweight to avoid being obstructive as previous works [8], [9].

A. *System Overview*

The proposed prototype is shown in Fig. 1. It is designed to be worn on the finger. The user can then swing their hand or finger at the direction they want to sense. When obstacle is detected, sound is emitted to notify the user.

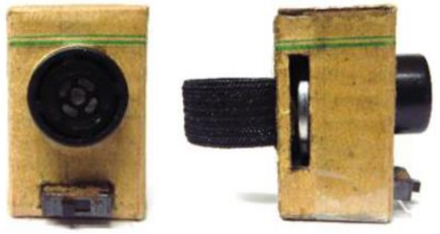

Fig. 1. Front (left) and side (right) view of prototype.

B. *Hardware*

Three core components in developing the prototype are input, processing and output. An ultrasonic sensor is used as the input module which is used to measure distance. For this prototype, Maxbotix HRLV-Maxsonar-EZ1 was selected due to its small form factor. It is capable of measuring distances from 30cm to 5m with resolution of 1mm.

The processor used in this prototype is the Arduino Pro Mini based microcontroller board. It has a small form factor and is easy to use. The microcontroller collects data from ultrasonic sensor and outputs the appropriate signal to alert user. The alert system uses smartphone speaker as the output.

C. *Detection Algorithm*

The method of detecting obstacle for this prototype is if an obstacle is detected, a sound is produced. The sound produced differs at different distance ranges. The shorter the distance between the obstacle and the prototype, the higher the frequency being emitted. When the obstacle is less than half a meter away from the prototype, a sound with frequency of 3000 Hz is emitted. When obstacle is less than a meter away, 2500 Hz is emitted. The frequency emitted in correlation with distance difference between prototype and obstacle is shown below (Algorithm 1).

Algorithm 1 Range detection

```
Read input from sensor, $x$
if $x < 0.5$m then
        Generate 3000 Hz tone
else if $x < 1$m then
        Generate 2500 Hz tone
else if $x < 2$m then
        Generate 2000 Hz tone
else if $x < 3$m then
        Generate 1500 Hz tone
else if $x < 4$m then
        Generate 1000 Hz tone
else if $x < 5$m then
        Generate 500 Hz tone
else
        Do nothing
end
```

V. TESTING AND EVALUATION

Two experiments were carried out to evaluate the performance of the prototype in detecting obstacles. The first experiment evaluates the ability of prototype to detect obstacles of different size and shape. The second experiment evaluates the potential of using the prototype in real life by testing it with participants.

A. *Experiment 1*

The first experiment was conducted in a controlled environment. The steps taken for the testing are carried out consistently shown in Fig. 2. The first step is to place a measuring tape on the ground so that distance between prototype and obstacle can be measured. The initial distance between prototype and obstacle is five meters. The distance is gradually shortened by moving the prototype at the aforementioned speed. The test is repeated five times. Throughout the experiments, a smartphone was used to record the frequency generated at different distance because it is difficult to determine the frequency generated when moving the prototype. The data is then analyzed and compiled in Table I.

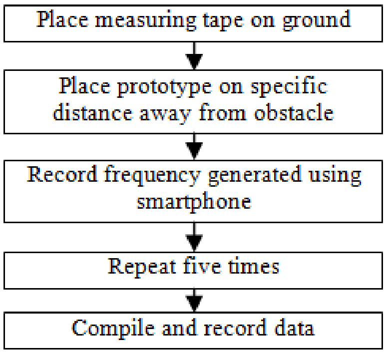

Fig. 2. Procedures taken in Experiment 1.

The obstacles used in this testing were found in both indoor (Fig. 3) and outdoor (Fig. 4) environments such as a wall, chair, table, car, lamp post and signage. The prototype was positioned at the average height of finger position [13]. For each obstacle, two tests were taken separately. The difference between the two tests is the walking speed towards the obstacle. Walking speeds of 0.8m/s and 1.2m/s were tested to simulate the average walking speed of people with visual impairment and people with normal vision respectively. The experiment was carried out five times for each test. A total of ten readings per obstacle were taken.

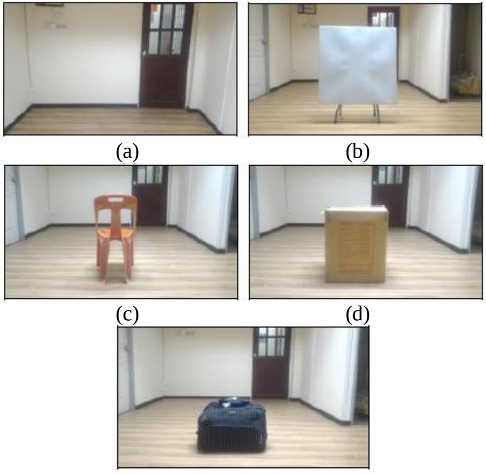
(a) (b)
(c) (d)
(e)

Fig. 3. Indoor obstacles: (a) wall, (b) table, (c) chair, (d) box, and (e) luggage.

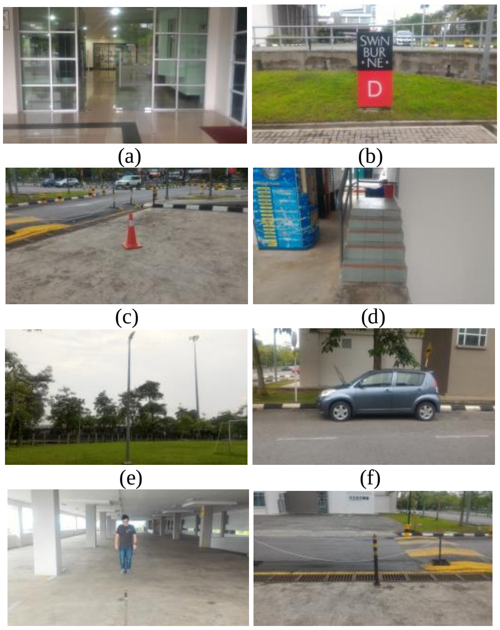
(a) (b)
(c) (d)
(e) (f)
(g) (h)

Fig. 4. Outdoor obstacle: (a) door, (b) sign post, (c) funnel, (d) stairs, (e) lamp post, (f) car, (g) human, and (h) post.

B. Experiment 2

Ten participants were invited for evaluation in the Experiment 2. The purpose, function and usage of the prototype were explained to the participants. Each participant was blindfolded and wore the prototype after the permission to proceed was obtained. Each blindfolded participant was assisted when he/she was walking to avoid falling. Fig. 5 shows one of the blindfolded participants walking towards a waist-level obstacle.

Fig. 5. A participant being blindfolded walking towards a waist-level obstacle.

The obstacles in the experiment were selected to cover different scenarios that could be encountered in real life situations. There were six obstacles for different purposes; wall column for object corner (Fig. 6 (a)), chair for irregular shape obstacle (Fig. 6 (b)), hanging boxes for waist-level (Fig. 6 (c)) and head-level (Fig. 6 (f)) obstacle, small box on the ground for minimum detectable range (Fig. 6 (d)), and table for obstacles with hollow body (Fig. 6 (e)).

The arrangement of the obstacles and path taken are shown in Fig. 7; from starting point to wall column, from wall column to chair, from chair to waist-level obstacle, from waist-level obstacle to ground obstacle, from ground obstacle to table, from table to head-level obstacle, from head-level obstacle to wall column, and this was repeated three times for each participant with a slight angle difference towards the obstacle on the next turn. This is to test the detection capability of the prototype when surface of an obstacle is not perpendicular to the prototype. Upon experiment completion, each participant was interviewed to obtain their opinions and thoughts on the experience of using the prototype.

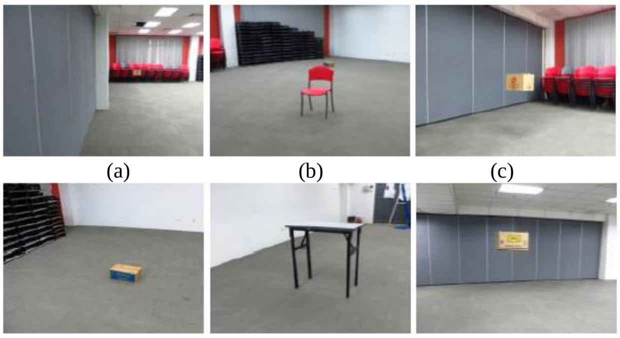
(a) (b) (c)
(d) (e) (f)

Fig. 6. Indoor obstacles: (a) wall column, (b) chair, (c) waist-level box, (d) small box, (e) table, and (f) head-level box.

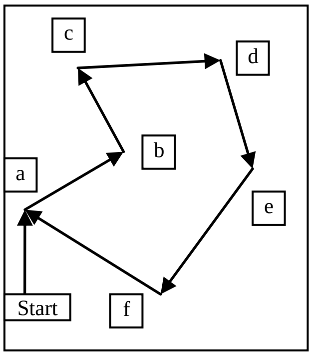

Fig. 7. Placement of obstacles.

C. *Experiment 3*

Further testing with participants on outdoor obstacles were conducted. In this experiment, low vision simulator googles were worn by the participants while using the prototype (Fig. 8). The experiment was carried out in an uncontrolled outdoor environment with real obstacles along the walking path within the campus. Following the feedback from Experiment 2, a modification on the prototype was made to increase the response speed of detecting obstacles.

Fig. 8. Participant with low vision goggles walking between two poles.

Fig. 9. Outdoor path with obstacles.

A different approach was taken to record and collect data in this experiment due to two factors; dynamic movement in an uncontrolled environment and location of obstacles. Dynamic movement of the participant makes it difficult to determine the sound generated without disturbing the participants by walking near them. Obstacles along the path are not necessarily detected unless a participant walk towards them and point the prototype towards the obstacles. Some of the paths with obstacles such as poles, trees and building columns are shown in Fig. 9. Audio and video recorders were used to solve these issues. The audio recorder was used to record the alert generated and is placed on the wrist of the participants and the video recorder was used to keep track of total obstacles along the path that are relevant to the sound generated. The collected audio and video files were then synchronized and the detection rate of detecting obstacles can be obtained.

VI. RESULTS AND DISCUSSIONS

A. *Experiment 1*

Table I shows the detection rates of indoor and outdoor obstacles in an ideal scenario (prototype aligned perpendicular to the obstacles). Large obstacles have high percentages of being detected such as a wall, table and box. One exception to this is the entrance door. When walking at speeds of 1.2m/s and 0.8m/s, the detection rates are 40% and 100% respectively. The speed difference may have caused the difference in detection rate. Slower walking speed gives the prototype more samples to process and thus higher detection.

Irregular shaped obstacles such as a chair and human decreases the detection rate of the prototype. The detection started decreasing when the distance between prototype and obstacle is greater than two meters. The detection rate of chair from two to three meters is 80% and 60% for walking speed of 1.2m/s and 0.8m/s respectively. This does not conform to the idea of slower walking speed increases obstacle detection rate. However, a more significant result from the same irregular shaped obstacle which is a human can be compared. When an obstacle is two to three meters away, the prototype can detect human at slower walking speed but not when walking speed is faster. Even if the detection rate is only 60%, it still signifies that it is capable of detecting the obstacle at slower walking speed.

TABLE I. DETECTION RATES OBTAINED WHEN PERFORMED UNDER CONTROLLED SCENARIOS

Obstacle	Walking speed (m/s)	Detection rate					
		0m to 0.49m	0.5m to 0.99m	1m to 1.99m	2m to 2.99m	3m to 3.99m	4m to 4.99m
Wall	1.2	100%	100%	100%	100%	100%	100%
	0.8	100%	100%	100%	100%	100%	100%
Table	1.2	100%	100%	100%	100%	100%	100%
	0.8	100%	100%	100%	100%	100%	100%
Chair	1.2	100%	100%	100%	80%	0%	0%
	0.8	100%	100%	100%	60%	0%	0%
Box	1.2	100%	100%	100%	100%	100%	100%
	0.8	100%	100%	100%	100%	100%	100%
Luggage	1.2	0%	0%	100%	100%	100%	100%
	0.8	0%	0%	100%	100%	100%	100%
Entrance door	1.2	100%	100%	100%	100%	100%	40%
	0.8	100%	100%	100%	100%	100%	100%
Sign board	1.2	100%	100%	100%	100%	100%	100%
	0.8	100%	100%	100%	100%	100%	100%
Stop funnel	1.2	100%	100%	100%	40%	0%	0%
	0.8	100%	100%	100%	100%	0%	0%
Stair	1.2	0%	100%	100%	100%	100%	100%
	0.8	0%	100%	100%	100%	100%	100%
Lamp post	1.2	100%	100%	100%	100%	100%	100%
	0.8	100%	100%	100%	100%	100%	100%

Car	1.2	100%	100%	100%	100%	100%	100%
	0.8	100%	100%	100%	100%	100%	100%
Human	1.2	100%	100%	80%	0%	0%	0%
	0.8	100%	100%	100%	60%	0%	0%
Post	1.2	100%	100%	100%	100%	60%	0%
	0.8	100%	100%	100%	100%	0%	0%

TABLE II. DETECTION RATES OBTAINED WHEN TESTED WITH PARTICIPANTS WITH LOW VISION

Obstacle	Column	Chair	Waist Level Obstacle	Ground Level Obstacle	Table	Head Level Obstacle
Successful detection	27	11	15	6	11	11
Total detection	30	30	30	30	30	30
Successful detection rate (%)	90	36.67	50	20	36.67	36.67

TABLE III. DETECTION RATES OBTAINED WHEN TESTED WITH PARTICIPANTS WITH LOW VISION

Test	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Detected obstacle	22	21	20	15	20	21	10	13	9	12	9	16	7	19	14	9	15
Total obstacle	31	26	21	22	28	29	13	26	11	15	12	22	11	21	21	11	24
Successful detection rate (%)	71	80.8	95.2	68.2	71.4	72.4	76.9	50	81.8	80	75	72.7	63.6	90.4	66.7	81.8	62.5
Time taken (s)	79	49	53	64	113	181	53	126	30	96	49	49	45	50	49	38	47
Distance travelled (m)	34.3	27.2	33	43.7	66.3	94	23	91.2	24.7	55.4	11.4	34.3	27.2	33	33	27.2	34.3
Average speed	0.44	0.55	0.62	0.68	0.59	0.52	0.43	0.72	0.81	0.58	0.23	0.7	0.6	0.66	0.67	0.72	0.73

A car is also considered an irregular shaped obstacle but the prototype is able to detect it correctly in both walking speed tests. This can mean that the size of the surface area affects the obstacle detection rate. The larger the size, the better the detection rate. Stop funnels and posts had lower detection rate when compared to large obstacle such as a wall. Both the obstacles can be detected at a distance up to three meters. Beyond that range, it is either a false detection or no detection. The surface of stop funnel and post is considered irregular and small which affected the detection rate.

Luggage and stairs detection rates differed from other obstacles. Both the obstacles can be detected up to five meters but had trouble being detected within one meter. A possible explanation to this is due to the height of both obstacles. As the prototype approaches the short obstacle, the surface being exposed decreases which reduces the detection rate in return.

B. *Experiment 2*

The detection rate of the prototype for different obstacles are shown in Table II. The highest detection rate among the six obstacles is the wall column with 90% successful detection rate. Waist-level obstacle is successfully detected at 50%. Chair, table and head level were successfully detected at 36.67%. The least detected obstacle is the ground-level obstacle with only 20% detection rate.

Many factors contributed to the success rates of detection such as size of the obstacle and the sensing angle of the prototype and obstacle. The height of the box used for ground-level obstacle is 16cm. The prototype is capable of detecting the obstacle of that height in ideal testing scenario where the prototype is aligned perpendicular to the obstacle. However, in real life, motion is involved and this affects the detection rate of the prototype. When participants move their hands or finger to detect an obstacle, the direction and angle between obstacle and prototype may not align to the ideal scenario. From the observation made during the experiment, participants had a tendency to lift their hands slightly and point the prototype upwards. This reduced the possibility of detecting a small and short obstacle which could be the reason for a low detection rate of 20%.

The detection rate of irregular shape objects is lower as discussed in Experiment 1. The irregular shape of a chair and the constant movement of the prototype may result in low detection rate of 36.67%. The table used in this experiment has a hollow body. The surface area of the table exposed to the prototype is very little; side of table top and leg of table only. The small surface area may have resulted in a low detection rate of 36.67%. The box used as head-level obstacle has a relatively large surface area and is regular shaped. However, the detection rate is only 36.67%. A possible explanation to this is the position and height difference between the prototype and obstacle. Similar with the ground-level obstacle, the prototype had no problem in detecting the obstacle in an ideal scenario where prototype was directly perpendicular to the obstacle. However, due to real life positioning of human's finger, the prototype cannot be perpendicular to the obstacle.

Successful detection rate of 90% was observed when the obstacle was a wall column. It was detected the most when compared to the other five obstacles. The surface area of wall column was big and the plane of the surface was flat and regular. These characteristics have increased the possibility of obstacles to be detected by the prototype.

The participants gave a few feedbacks that could improve the functionality of the prototype. They suggested a louder audio feedback as the volume was low when frequency was low. They also suggested the prototype to have a higher response speed. They expressed the unfamiliarity in using the prototype caused some confusion particularly the directing the prototype to perform detection.

C. *Experiment 3*

Data collected from the audio and video recording mentioned previously is tabulated in Table III. A total of 17 walking tests were recorded with varying distances, rate of obstacle detections and time taken to complete the path. Average walking speed of the participants can be calculated based on the distance travelled and time taken.

It is observed that the detection rate increased in Experiment 3. The average successful detection rate of obstacle in Experiments 2 and 3 are 45% and 74% respectively. The increase of response speed of the prototype increased the rate of detecting obstacles by 29%.

Fig. 10 depicts the relation between detection rate of the prototype and average walking speed of the participants. The wave form in the plot is not linear, exponential or logarithmic. Though there is a slope pattern found between detection rate of 60% and 80% which can signify the relation of detection rate with walking speed such as low walking speed increases the rate of detecting obstacle. It is invalid to prove that relation because high detection rate of above 80% can be found in participants with a fast walking speed.

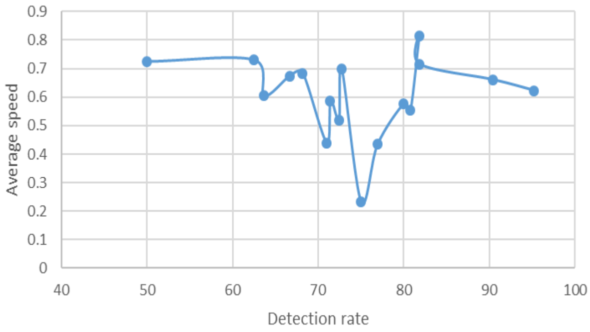

Fig. 10. Relation between rate of detecting obstacle and average walking speed of participant.

VII. CONCLUSIONS

This research aims to assist the mobility of people with visual impairment by utilizing low cost sensors to create a smart obstacle detection prototype. The prototype is a low cost and low maintenance finger-mounted obstacle detector that was built from an ultrasonic sensor, an audio generator and a microcontroller. Three set of experiments were conducted. The first experiment was conducted to determine the detection rate on indoor and outdoor obstacles of different sizes and shapes in a controlled environment. The results showed it was capable of detecting real life obstacles of different sizes and shapes. The second experiment was conducted to test the prototype with participants wearing blindfolds (no vision simulator) and walking in an indoor environment filled with real life obstacles. The results, however, showed lower detection rates for obstacles in different scenarios. The third experiment was conducted with participants wearing low vision simulators walking in outdoor environment, and the detection rates were better than those obtained in the second experiment. It is clear that the prototype works better for users with low vision than no vision.

For future prototype improvement, feedbacks taken from participants are to be considered such as increasing the speaker volume and further increasing the prototype detection speed. This will involve a study to optimize the energy consumption, performance, size, compactness and usability of the finger based obstacle detection. In addition, materials used to attach the prototype onto the index finger of the user will be surveyed and enhanced to firmly secure the prototype when pointing at obstacles.

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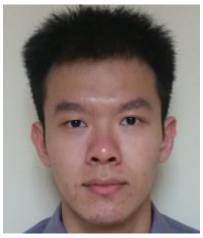

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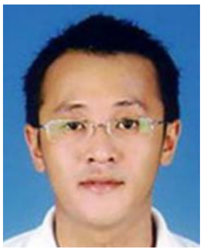

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