Pathfinder: Device for Obstacle Detection and Avoidance to Help The Mobility of Visually Impaired People

An Undergraduate Special Problem

In partial fulfillment of the requirements

for the Degree of Bachelor of Science in Computer Science

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Biographical Sketch

The author, Moshe F. Nacu, is a BS Computer Science student form the University of the Philippines Los Baños. Born on the 19th of November 1999, he is the oldest among three siblings. His hobbies are video games, watching anime, tinkering with small electronics, and crafting costumes out of foam and cardboard. He is a proud member of the UPLB Computer Science Society, UP Alliance of Gamers, and the UPLB Gabay Volunteer Corps.

Abstract

Pathfinder is a wearable computer vision device that aims to assist in the mobility of the visually impaired. The Shi- Tomasi Algorithm was applied to detect the feature points and the obstacles along the path. The software is installed on a Raspberry Pi. The input is a live video feed captured by the Raspberry Pi Camera. The device gives directions to the user using sounds. Nine users participated in testing the device and they agreed that the device was successful in redirecting them to avoid the obstacles along the path that they were traversing.

I. Introduction

A. Background of the Study

According to the World Health Organization [1], approximately 2.2 billion people are affected by visual impairment which may affect one's ability to navigate their way around. This raises the question of how a visually impaired person can make their way around without running into objects and people. Navigation varies from people with mild visual impairment to those who are completely blind. In the case of those with total lack of vision, it takes years of practice to be able to get around on their own. However, cases wherein one immediately loses their sight arise a need for assistance in navigation without having to spend years on practice. Thus, the need for a device that can aid the visually impaired.

A study was made in 2012 wherein digital image processing was used to identify obstacles and lateral doors along a hallway. This study utilized the counting zero-crossings of image derivatives, histogram of binary edges, and the Law's texture energy masks algorithms to detect obstacles along the way. The study used the Canny edge detector to identify the edges of doors and corridors [2].

A 2015 study conducted by Estremos utilized the Shi-Tomasi algorithm to detect corners in obstacles. The Lucas-Kanade algorithm helps predict where a moving obstacle would go. This system notifies the user which direction they should take to avoid the said obstacle [3].

This paper aims to create a similar wearable system using a Raspberry Pi 4. A camera module will be used to collect the video or images to be digitally processed. This system is intended to be portable and accessible to the visually impaired.

B. Statement of the Problem

Visually impaired people have developed multiple ways of traversal and navigation. Most of their methods, however, assume that the obstacles ahead of them are static and are thus unable to prepare in the case of a moving obstacle. Methods such as the white cane and guide dogs take up space and may also inconvenience other people. To address such a problem, this study aims to develop a wearable device which can detect static and moving objects and can guide its users to avoid them.

C. Significance of the Study

This study aims to develop a system that will assist visually impaired people with profound low vision to total blindness. It would help enable these visually impaired people to confidently traverse rooms, hallways, and outdoor areas. The device would be able to detect obstacles in front of the user and direct them to avoid said obstacle. By guiding the user around the obstacle, they will not have to worry about running into objects and people while walking.

D. Objectives

This study aims to create a portable device prototype which will help the navigation of visually impaired people

- To use digital image processing “techniques” for obstacle detection;
- To detect obstacles within 3 meters from the user; and
- To notify the user of the obstacle and redirect them to avoid it.

E. **Scope and Limitations**

The study aims to cater to visually impaired people with profound low vision to people with total blindness. People with profound low vision have a visual acuity of 20/500 to 20/1,000 [4]. The study will consider static and moving objects as obstacles whether they are living or non-living. The environment this is meant for are hallways and open areas such as streets and plazas. The environment assumes that the user is walking along a straight and unending road or hallway.

Although the study aims to guide users around an obstacle, it would not be able to detect obstacles that are hanging or are coming from behind the user. Due to the angle of the camera, obstacles that are behind and directly underneath it cannot be detected. Hanging obstacles and low head room are not detected since the study focuses on obstacles found below the chest. Users are expected to walk in a straight line. The user experience would change when it comes to the lighting of the environment. The system is expected to work in broad daylight and in well-lit areas under artificial lighting.

II. Review of Related Literature

Navigation has always been a challenge for the visually impaired. There are a few methods that a blind person can employ in order to navigate their way through such as the white cane, guide dogs, and echolocation [5].

First, a person can scan their immediate environment by swinging a white cane in an arc in front of them. By swinging the cane and touching it to the ground, they can identify obstacles and curbs [6].

Second, guide dogs are trained to perform tasks such as directing its owner along known paths and avoiding obstacles like stairs or railings. The dogs can also refuse commands, such as walk, when faced with tight spaces or ongoing traffic. The dogs also follow commands such as look for empty seats or fetch an object [7].

Lastly, echolocation is a navigational method used primarily by bats and dolphins utilizing the bounce-back of sounds to map their environment. Some humans, such as Brian Borowski, have developed the skill for echolocation. Sharp clicking sounds help him listen to echoes which help him map his environment except in instances with too much background noise [8].

Jacobson [9] talked about how wayfinding can help the visually handicapped in navigation. He talked about using a Global Positioning System (GPS), a Geographical Information System (GIS), and a voice synthesizer to develop a Personal Guidance System (PGS). The PGS can determine the best routes the user can take and can guide them there using the voice synthesizer.

Bousbia-Salah, Fezari, and Hamdi [10] devised a navigational system for the blind which eases navigation on predetermined routes using an accelerometer and a microcontroller. These devices calculate distance and compare them to previous measurements which lessen user location estimation.

Navigation using GPS and building layouts have been proposed. The use of these technologies could guide the user to their desired location assuming the area has the appropriate sensors [11].

Over the years, technology has given us a way to identify objects through ultrasonic sensing and through a camera using digital image processing. Bousbia-Salah, Redjati, Fezari, and Bettayeb [12] developed a device that uses ultrasonic sensors to detect obstacles. The user is notified if there is an obstacle ahead using a pair of small vibrators fixed onto the clothes of the user.

Another device utilizing ultrasonic sensors was devised by Siddhartha, Chavan, and Uma [13]. Unlike the previous device, this notifies the user using voice commands played from the smartphone.

Digital image processing has provided big opportunities in the application of navigation. Moreno, Shahrabadi, José, Buf, and Rodrigues [2] were able to utilize digital image processing to identify lateral doors in a hallway. Their system was also able to identify obstacles along the way.

Estremos [3] utilized the Shi-Tomasi and Lucas-Kanade Algorithm to detect corners and predict the possible direction an object may follow.

This study aims to create a camera-based obstacle detection system using a Raspberry Pi 4 with a camera module. Obstacle detection will make use of the Lucas-Kanade and the Canny edge detection Algorithm.

III. Methodology

A. Instrument Build Specifications

The device was composed of a Raspberry Pi 4 motherboard with a 16GB storage and 4GB ram, a 5MP Raspberry Pi camera module Rev 1.3 running at 30FPS, and a 12000mAh power source (See Figure 1). The camera provided the input which was processed by the Raspberry Pi. The embedded program identified obstacles and decided the path that the user took. The system ran on Raspbian Buster, a Debian-based operating system for the Raspberry Pi. The device was worn around the chest area using a lanyard and the battery pack was strapped around the waist (See Figure 2). The device was placed inside a customized 3d printed casing. The casing was divided into three components. The first component was the base which includes "rings" to attach the straps and lanyard (See Figure 3). The second component was the cover which slides over the base (See Figure 4). The third component was attached to the cover and it held the camera in an angle (See Figure 5). Peizoelcetric buzzers were connected for the sound output.

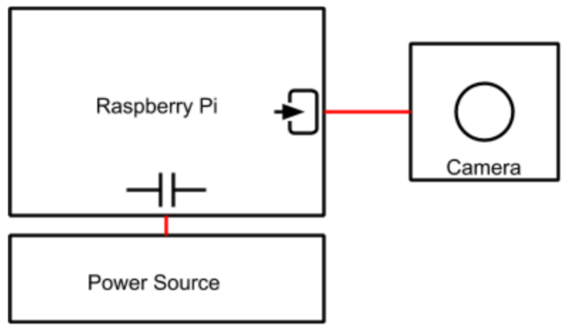

Fig. 1. Diagram of Device Connections

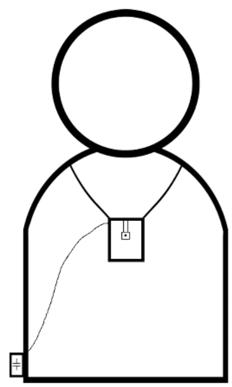

Fig. 2. Diagram of the Device Worn by a User

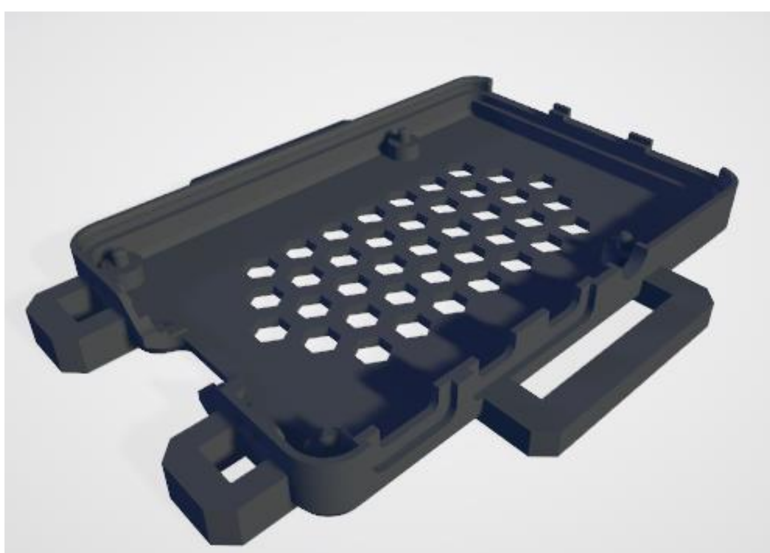

Fig. 3. 3D Model of the Base of the Casing

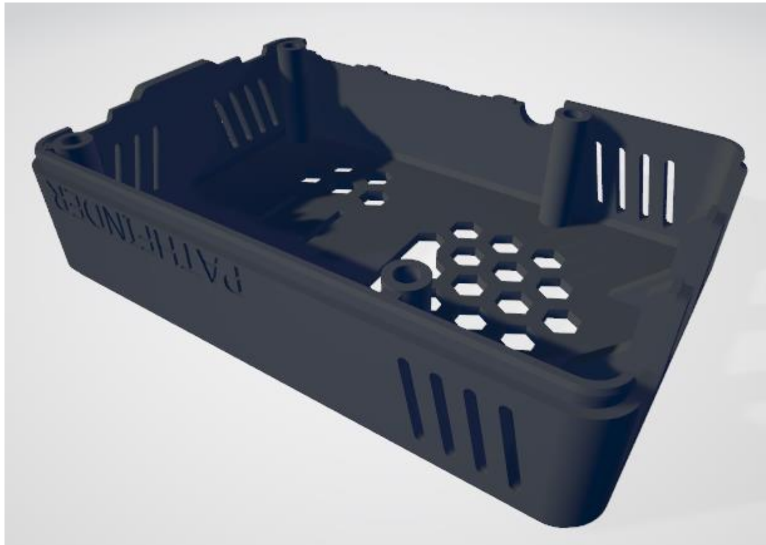

Fig. 4. 3D Model of the Cover of the Casing

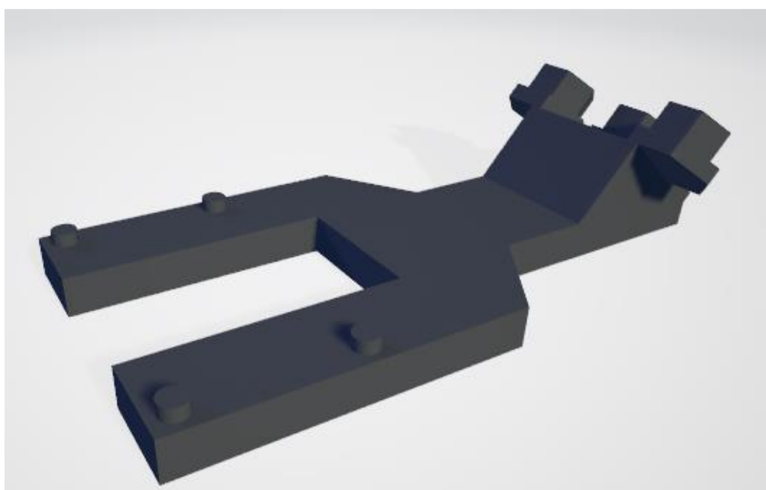

Fig. 5. 3D Model of the Camera Stand of the Casing

B. Obstacle Detection

1. Setting up the Search Space

The search space was composed of three rows and three columns (See Figure 6). The search space was similar to the search space of

Estremos [3]. The first row represented the area after 3 meters which was marked by the first horizontal line. The 3 meter mark was based on car sensors which have a 2-2.5 meter range [14]. 3 meters was also chosen as a safe distance based the study by Cecílio, Duarte, and Furtado whose study utilized a distance of 2 to 5 meters [11]. The third row represented the area 1 meter from the user. Obstacles within this row was evaluated for their edges. The bottom row was divided into three columns and served as separate regions of interest (ROI). Each regions of interest were differentiated by color with the left being blue, the center being green, and the right being red. The top left region contained a timer which shows how much time in seconds have passed. Each ROI had a counter in their upper right corner of the number of points detected within itself.

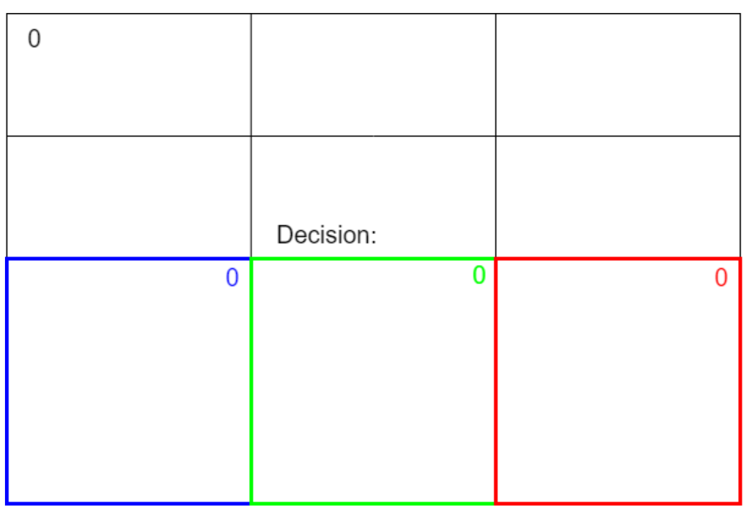

Fig. 6. The Search Space

2. **Pre-processing**

    Grayscale was first be applied into the frame for better measurement of the varying pixel intensity. Noise reduction was accomplished by applying a Gaussian blur to smooth the frame.

3. **Edge Detection**

    The Shi-Tomasi Algorithm was applied to detect the feature points of an object. The feature points are the basis for detected obstacles.

4. **Identifying Obstacles**

    The bottom row of the search space, divided into three parts, served as the region of interest. The number of feature points per region was counted. A threshold of 0.01 determined a feature point. Points Within the search space were counted as obstacles.

C. Obstacle Avoidance

If an obstacle appeared in any of the three areas, the program directed the user to the nearest area with the least amount of feature points via the use of two piezoelectric buzzers. The user was directed to step to the left if the left buzzer beeps, right if the right buzzer beeps, and forward if both the left and the right beeps.

D. End-user Testing

To measure the performance of the system, subjects navigated their way along an obstacle-filled path. Due to the limit of resources brought by the Covid-19 pandemic, the scene or the environment for the testing was a 6-meter driveway in Diliman, Quezon City (See Figure 7). The tests were conducted outdoors from 3pm - 5pm. There were three trials. These trials are meant to compare the effectiveness of the different methods of navigation. The first trial required the user to traverse the obstacle-ridden path with only a blindfold. The second trial required the user to traverse the same pathway with a blindfold and a cane. The third trial required the traversal of the same pathway using the device itself. The time they took to complete the course was recorded as well as the number of mistakes they made. The respondents of the trials are all able-bodied people with a height ranging from 152cm to 175cm. The respondents are not visually impaired and were thus made to wear a blindfold. The test subjects were selected based on their availability and proximity to the test environment due to the Covid-19 pandemic. The subjects then answered a survey comparing the three trials (See Tables 2-4).

Fig. 7. Test Environment: 6-meter Driveway with Good Weather Conditions, Lighting, and Obstacles

IV. **Results and Discussion**

A. Device

The completed device (See Figure 8) was attached to lanyards and connected to a power bank. The device was worn around the neck of the user up to the chest (See Figure 9).

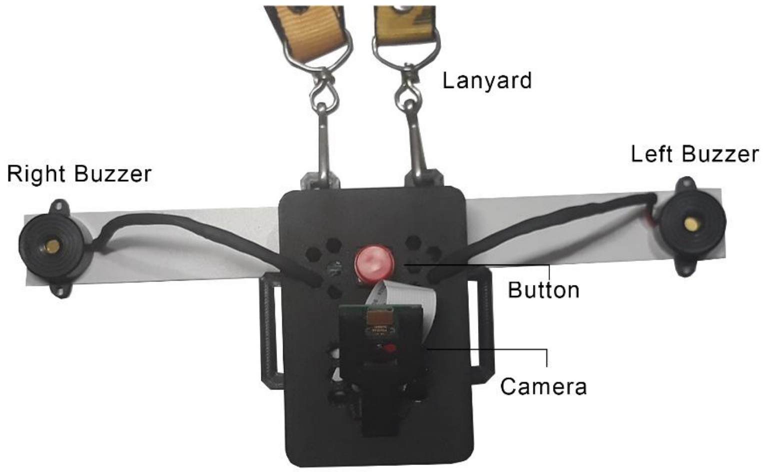

Fig. 8. Completed Device

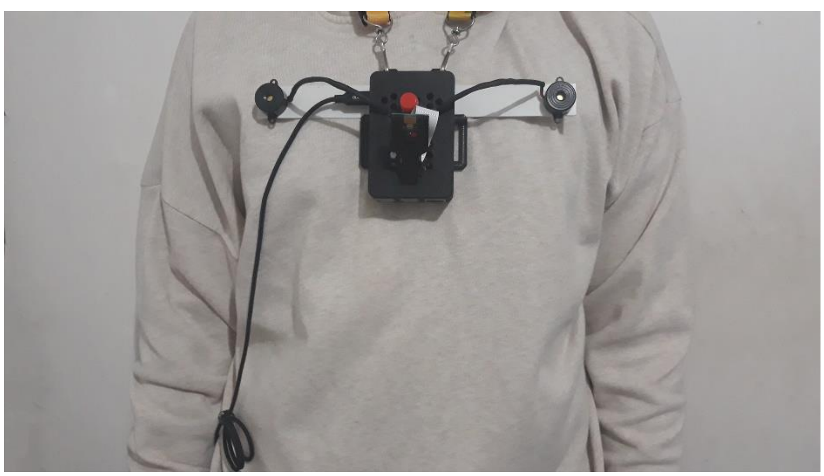

Fig. 9. Device Worn by a User

B. **Development of the Obstacle Detection Software**

During the pre-processing stage, grayscale and Gaussian blur are applied unto each frame. The Shi-Tomasi Algorithm is applied to detect feature points on these frames. The search space and the feature points are applied into the original frame for example purposes. Figure 10 Shows how a frame would look like per step. The top left image shows the original image. The top right shows the image that has been applied with grayscale and a Gaussian Blur. The bottom left images applies the Shi-Tomasi Algorithm unto the grey and blurred image. The bottom right images displays the feature points and search space unto the original image.

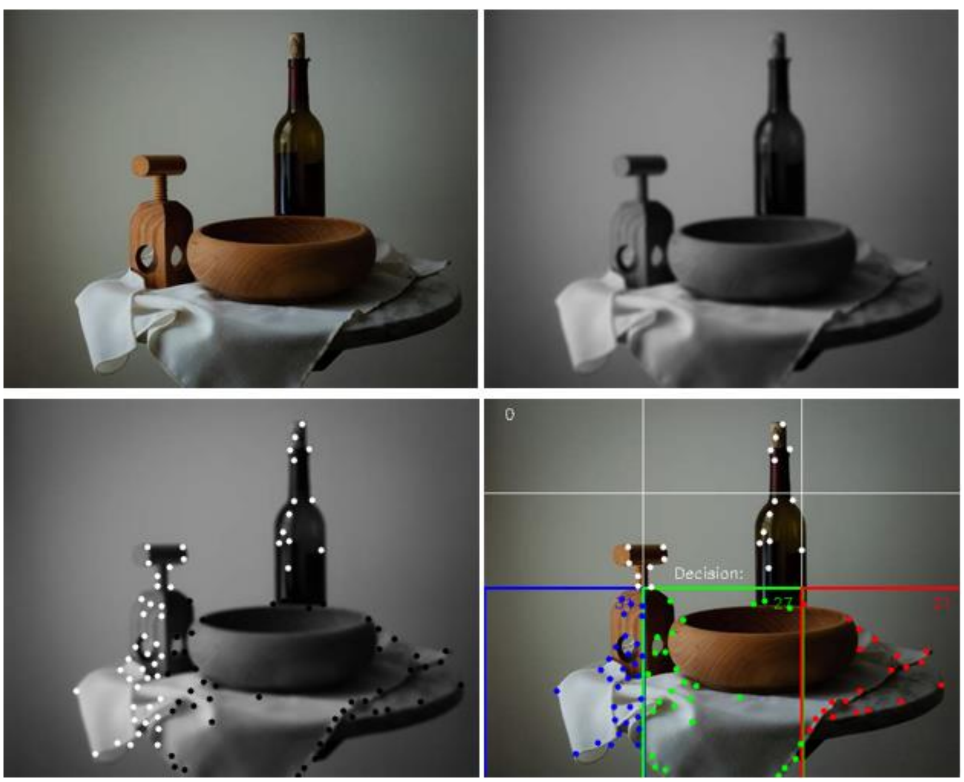

Fig. 10. Outputs per Methodological Step

C. Testing the Accuracy of the Obstacle Detection Software

Testing the device was achieved by recording the number of obstacles detected by the system (D) and the number of obstacles detected by a human observer (G). Testing comprised of 10 different paths with varying amounts of obstacles (See Figures 16-25, Appendix). The precision of the system pertains to the relevance of the points detected while the recall pertains to the correctness of these points. The precision and recall were computed through these formulas [15].

$$Precision = \frac{|G \cap D|}{G}$$

$$Recall = \frac{|G \cap D|}{D}$$

Table 1 gives us the data and results for testing the precision of the system. The system ended up with an average precision of 83\% and an average recall of 100\%. Misdetections from the system were caused mostly by the irregular coloration of the ground, shadows, and parts of the background captured (See Figure 11). Portions of the ground with a significantly darker shade were treated as feature points while transparent looking objects were ignored by the system. The device also performed poorly during the instances that the camera had a higher angle which fails to detect obstacles close to the use. This also counted some of the background as obstacles, thus affecting the decision making.

Path Number	Human Found (G)	System Found (D)	$G \cap D$	Precision	Recall
1	8	6	6	0.75	1
2	9	8	8	0.89	1
3	10	8	8	0.8	1
4	10	8	8	0.8	1
5	11	11	11	1	1
6	12	11	11	0.92	1
7	13	11	11	0.85	1
8	14	10	10	0.71	1
9	15	12	12	0.8	1
10	16	12	12	0.75	1
Average				0.83	1

Table 1. Precision Testing Results

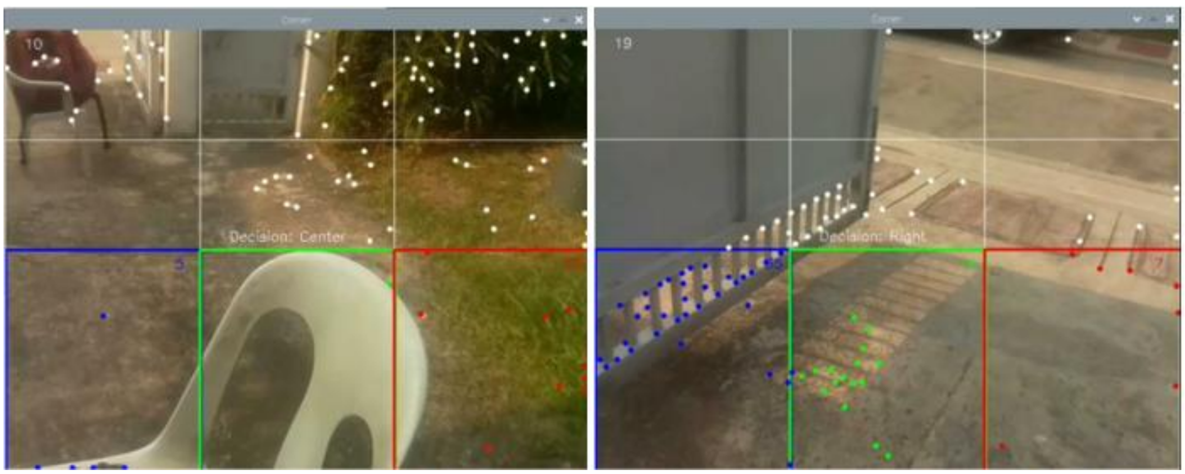

Fig. 11. Examples of Misdetections

The device works by tracking the feature points as the user moves forward. It then directs the user to step to a direction of the least amount of detected obstacles. The device provides instructions to the user by playing a sound through the buzzers for 20 milliseconds every 2 seconds. The device directs the user to step to the left if the sound comes from only the left buzzer, and step to the right if the sound comes from only the right buzzer. If the sound comes from both buzzers simultaneously, the user is instructed to keep moving forward. The sequence of frames in Figure 12 shows the device counting the feature points and flashing the previous decision.

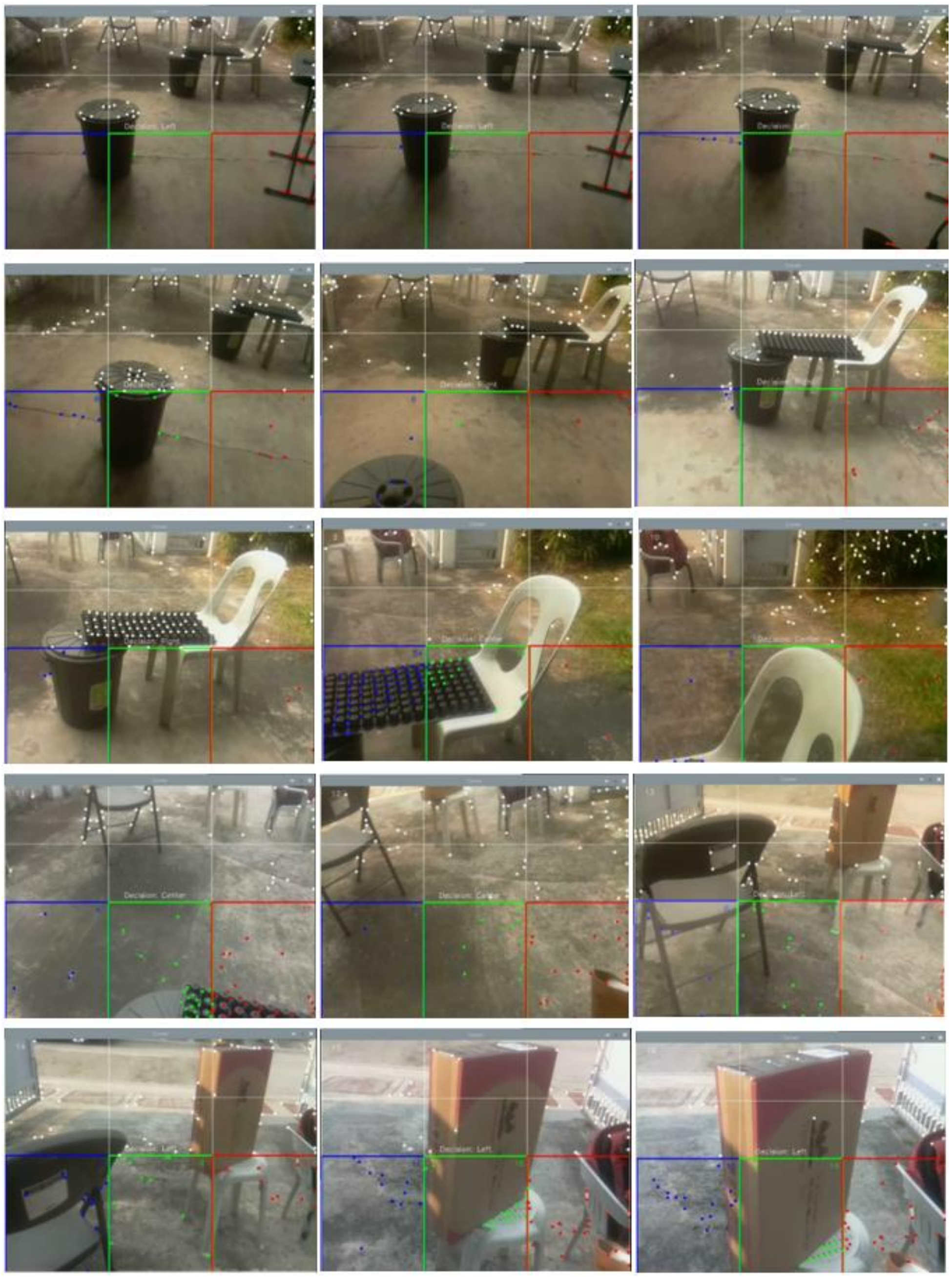

Fig. 12. Sequence of Frames showing the Tracking of Feature Points

D. Testing the Device

Testing was done by letting the respondents traverse an obstacle filled path three times. The first test required the user to traverse the path with only a blindfold. The second test required the user to traverse the same path with a blindfold and a cane. The third test required the device to traverse the path. The time they took to complete the course was recorded as well as the number of mistakes they made. After the tests were completed, responses from the users were taken to prove the effectiveness on the system compare to the other tests. After a 10-minute testing phase, the users were made to answer a survey based on the tests as seen in tables 2-4. The whole survey follows a rating scale with the values of 1 - Strongly Disagree, 2 - Disagree, 3 - Neither agree nor disagree, 4 - Agree, and 5 - Strongly agree.

Questions for Blindfold Only	
1	It is easy for me to navigate through the path.
2	It is easy for me to adjust to walking blindly.
3	Given that I am blindfolded, I need a guide in order for me to easily navigate through the path.

Table 2. Category 1: Blindfold Only

Questions for Blindfold with cane/stick	
1	It is easy for me to navigate through the path with a cane.
2	Navigating through the path is easier with a cane than without a cane.
3	It is easy for me to detect the obstacles along the path.
4	The cane is useful in finding the obstacles along the path.
5	I can rely on the cane in finding the obstacles along the path.

Table 3. Category 2: Blindfold with Cane/Stick

Questions for System use	
1	It is easy for me to use the system.
2	It is easy for me to understand the directions given by the system.
3	I am able to follow the directions given to me by the system when navigating through the path.
4	Navigating through the path is easier when using the system than just navigating without any tool or assistance.
5	Navigating through the path is easier when using the system than using the cane.
6	Navigating through the path is easier when using the system and the cane at the same time.
7	The directions given by the system are helpful in successfully navigating through the path.
8	The directions for navigating are given by the system in a timely manner.
9	The directions given by the system were reliable.
10	The system is useful in navigating through the path.
11	The system is able to properly detect the obstacles along the path.
12	The system works properly without any errors encountered.
13	The system works but with minimal errors encountered.
14	The system works but there are a lot of errors encountered.
15	The system does not work at all.

Table 3. Category 3: System Use

The ratings for category 1 as seen in Table 5 is based on their own experience of being blind for the first test. This test gave the users an idea on how to move around without their sight.

Questions	Users' Response									Mean
	1	2	3	4	5	6	7	8	9	
1	2	2	4	4	1	3	2	2	1	2.33
2	2	3	5	4	1	3	4	3	1	2.89
3	5	3	4	5	5	5	4	4	5	4.44

Table 5. User Ratings for Category 1

Figure 13 summarized the user ratings of table 5 in terms of the frequency of a certain answer per question. Table 5 provides the average rating per question. A low average rating for question 1 means that the respondents faced difficulty on navigating with a blindfold. For question 2, an average rating of 2.89 means that the respondents were divided when it came to adjusting to the blindfold. However, the high average for the third question means that the respondents think that a guide would help them navigate blindly much easier.

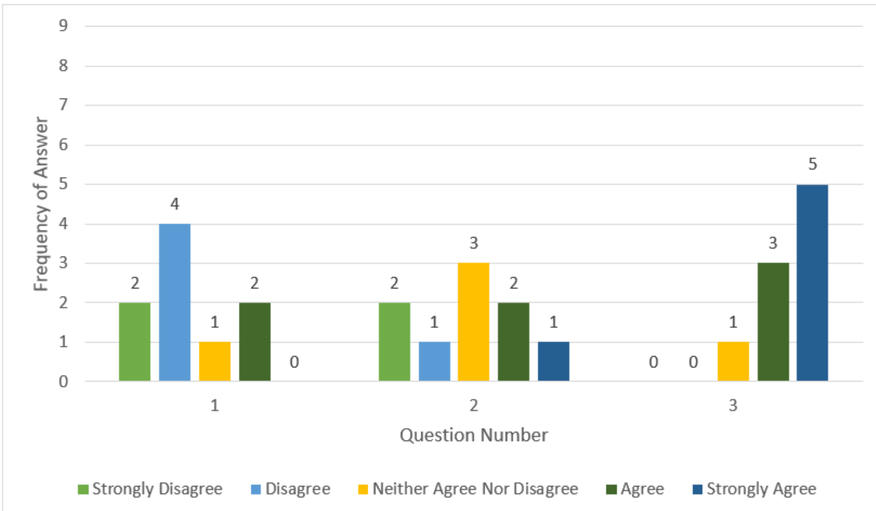

Fig. 13. Frequency of Responses for Category 1

Questions	Users' Response									Mean
	1	2	3	4	5	6	7	8	9	
1	4	2	4	4	3	5	5	5	4	4
2	5	4	5	4	4	5	5	5	5	4.67
3	4	3	4	3	4	5	5	5	5	4.22
4	5	3	4	5	4	5	5	5	5	4.56
5	4	3	5	3	4	5	5	5	5	4.33

Table 6. User Ratings for Category 2

The ratings of the respondents for category 2 can be seen in table 6. This test focused on the respondents using a cane along with the blindfold to navigate through the same path. The questions for this category uses the same 1-5 rating.

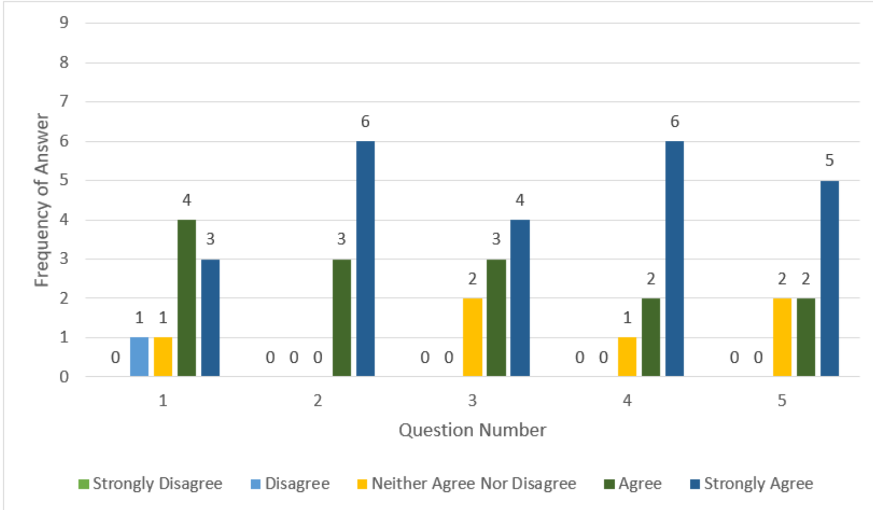

Fig. 14. Frequency of Responses for Category 2

Figure 14 gives us the frequency of the answers for category 2. The responses for category 2 can be summarized into the average answers as seen in Table 6. All the questions produce a high average which means that the addition of a cane greatly improved their performance in navigating blindly.

Questions	Users' Response									Mean
	1	2	3	4	5	6	7	8	9	
1	3	4	3	3	4	5	2	2	3	3.22
2	3	4	2	2	4	4	4	3	3	3.22
3	3	4	3	3	4	5	2	3	4	3.44
4	3	3	4	5	3	5	2	2	4	3.44
5	2	4	3	4	3	3	2	2	2	2.78
6	3	3	2	3	5	5	4	4	2	3.44
7	3	4	4	3	5	5	4	4	4	4
8	3	4	4	4	5	3	3	4	4	3.78
9	4	3	3	4	4	4	3	4	4	3.67
10	4	4	4	4	4	4	4	4	4	4
11	4	4	4	4	4	4	2	4	4	3.78
12	3	3	3	4	2	3	2	3	4	3
13	4	4	4	4	2	3	4	2	2	3.22
14	2	4	4	5	3	3	4	4	4	3.67
15	3	4	5	5	5	4	5	5	5	4.56

Table 7. User Rating for Category 3

Table 7 gives us the ratings for category 3. This category involved the use of the device to traverse the path. The questions found in table 4 can be grouped into different categories. Questions 1-3 focus on the adaptability of the user to the device and its features. Questions 4-6 describe the effectiveness of the device. Questions 7-11 describe the usefulness of the device. Questions 12-15 focus on the reliability of the Device. Questions 14 and 15 are negative questions meaning a low score is positive while a high score is negative. The scores for questions 14 and 15 were reversed in table 7 to continue the trend of positive outlooks. The revised question 14 was "The system did not work and there were multiple errors encountered." Question 15 was revised as "The system works." The questions for this category uses the same 1-5 rating.

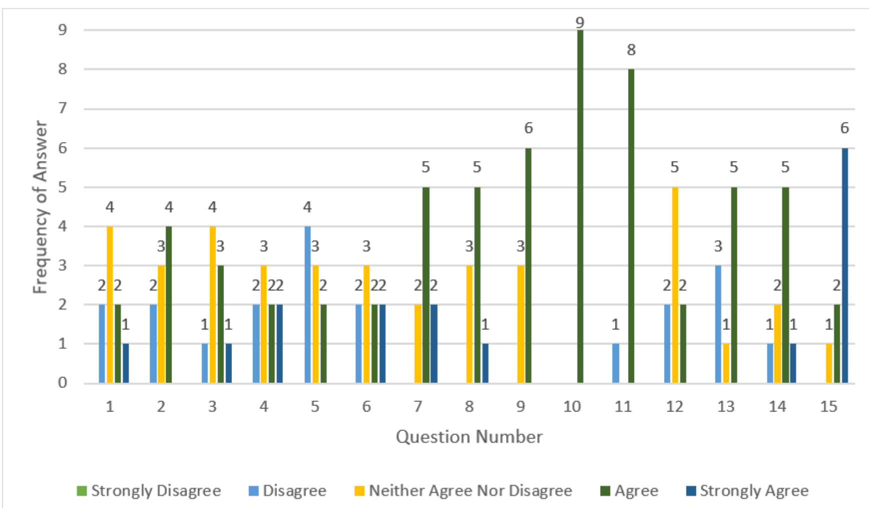

Fig. 15. Frequency of Responses for Category 3

Figure 15 gives us the frequency of answers per item. Table 7 also gives us the average answer per question. The questions for adaptability give us an average rating which means that the respondents were inconclusive on the matter. Questions on the effectiveness of the device also give an average rating meaning the users find it within the level of the cane. The questions for usefulness produced much higher averages meaning the device can be seen as a useful alternative. When it comes to reliability, the ratings ranged from average to high meaning the device is quite reliable to use.

Test No.	User									Min	Max	Mean
	1	2	3	4	5	6	7	8	9			
1	20.29	20.08	16.31	17.04	31.88	36.64	43.55	22.62	38.00	16.31	43.55	27.38
2	28.24	17.21	18.07	17.02	22.90	20.91	36.64	24.22	32.62	17.02	36.64	24.2
3	36.92	16.95	19.70	18.37	29.33	41.23	40.65	23.00	39.70	16.95	41.23	29.54

Table 8. Time Taken to Complete the Trials

Table 8 gives us insight on the time it took, in seconds, for the respondents to complete each trial. Table 8 is summarized through average time it took to complete each trial. The first trial was completed in an average of 27.38 seconds. The second and third trial were completed in an average of 24.2 and 29.54 seconds respectively. Based on the average time, the second trial proved to be the fastest method while the third trial was the slowest.

Test No.	User									Min	Max	Mean	Mode
	1	2	3	4	5	6	7	8	9				
1	6	3	2	2	4	3	3	2	6	2	6	3.44	2, 3
2	2	0	0	0	0	0	0	0	0	0	2	0.22	0
3	2	0	0	0	2	2	2	2	1	0	2	1.22	2

Table 9. Number of Mistakes Made per Trial

Table 9 presents the number of mistakes each respondent made per trial. It is summed up in Table 9 in the form of the average mistakes and the mode of mistakes. The blindfold only test gave us an average of 3.44 mistakes. The test was bimodal giving 2 and 3 as the modes. The blindfold and cane test produced the least amount of mistakes with 0 mistakes as the most common case. The device test brought minimal mistakes with an average of 1.22.

There were a couple of challenges that were faced during the study. One challenge was that of the sound which the buzzers made. Since the buzzers were the same model, they produced the same sound with their only distinction being the direction that they were coming from. Another challenge was that the angle of the camera would differ between people especially those with a significantly elevated chest. The angle of the camera affected the results since it was not able to capture the obstacles closer to the user, thus affecting the effectiveness of the device.

V. Conclusion

In this paper, Pathfinder was created to avoid obstacles by detecting feature points and creating a decision maker. The result of this study showed that the device, upon asking the respondents if the device works, had an average rating of 4.56 on a scale of 1-5. In terms of average mistakes made during testing, the device had an average of 1.22 mistakes which is just behind the cane with an average of 0.22 mistakes. This means that a different type of portable guide was effective in guiding the visually impaired. The study shows that although the cane was more effective, the device was not far off from becoming an option for obstacle detection for the visually impaired. With the help of this device, we have been able to instruct users to avoid the obstacles in their way thus avoiding accidents.

VI. Recommendations

Future work on this study can base the decision maker on the distance covered instead of time in seconds. This method can take into account the walking speed of the user. Future studies can also add wall detection and a path follower to be able to expand the scope of the environment. Future development of the project can make use of buzzers with different sounds in order easily distinguish left from right. A small gimbal can be attached to the camera to make sure that it is always in the right angle.

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APPENDIX

Paths used in Testing the Accuracy of the Obstacle Detection Software

Fig. 16. Path 1

Fig. 17. Path 2

Fig. 18. Path 3

Fig. 19. Path 4

Fig. 20. Path 5

Fig. 21. Path 6

Fig. 22. Path 7

Fig. 23. Path 8

Fig. 24. Path 9

Fig. 25. Path 10