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

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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 these features were the basis for detecting the obstacles along the path. The software was installed on a Raspberry Pi. The input was a live video feed captured by the Raspberry Pi Camera. The device gave directions to the user using the sounds produced by the buzzers attached to the device. The application was tested in terms of the accuracy of the obstacles being detected and it yielded 83% precision and 100% recall. In testing the usability of the device, nine blindfolded users were asked to wear the device while walking through a path with obstacles. They evaluated the device in terms of how quickly they were able to adapt to using it, effectiveness, usefulness, and reliability. Although the users were not able to quickly adapt to using the device in traversing the path, they agreed that the device was somewhat effective in helping them avoid the obstacles. They also agreed that the system was useful and reliable in guiding the visually-impaired.**

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 Laws 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. Specifically, the study aims to:
- 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 considered static objects as obstacles. The environment this is meant for was 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 aimed 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 and height 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. The device does not feature a stop function for when it encounters a dead-end or wall. 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. Testing of the device was done on blindfolded users due to the limit of resources brought by the Covid-19 Pandemic.

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, Jos, 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 Shi-Tomasi Algorithm.

III. THEORETICAL FRAMEWORK

The Shi-Tomasi Algorithm is an algorithm used in this study for the purpose of corner detection. Corner detection is done by detecting feature points in an image. The Harris Corner Detector and Shi-Tomasi Algorithm are some of the most used and well-known algorithms for corner detection.

The Shi-Tomasi Algorithm is based on the Harris Corner Detector but with a small difference in their computation [14] [15]. Corner detection in both algorithms require for a score (R) to be computed for each pixel. Unlike the Harris Corner Detector, the Shi-Tomasi algorithm simplifies the computation of R by using only the eigenvalues (λ_1, and λ_2) for computation. The computation for R is done with this formula [14] [15].

$$R = min(\lambda_1, \lambda_2)$$

After applying a threshold, if R is greater than the threshold value, it is classified as a corner [15].

IV. 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.
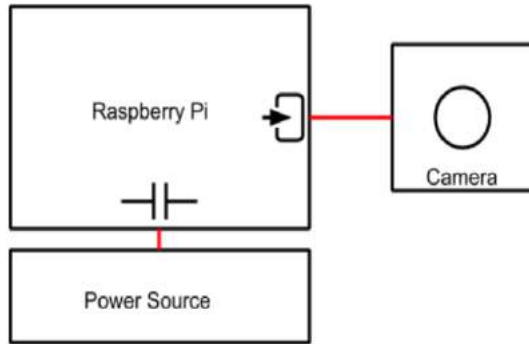
Fig. 1.   Diagram of device connections
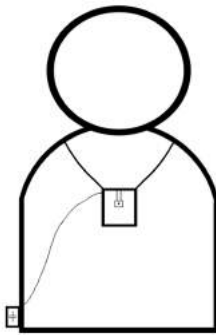

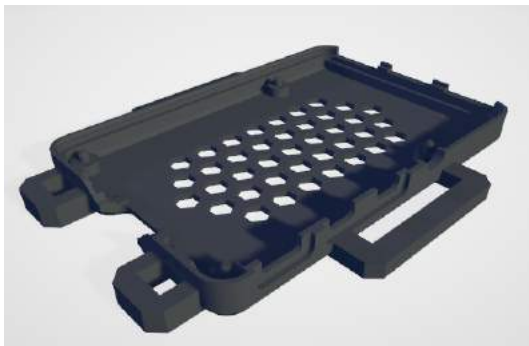Fig. 2.   Diagram of the device worn by a user

Fig. 3.   3D Model of the base of the casing
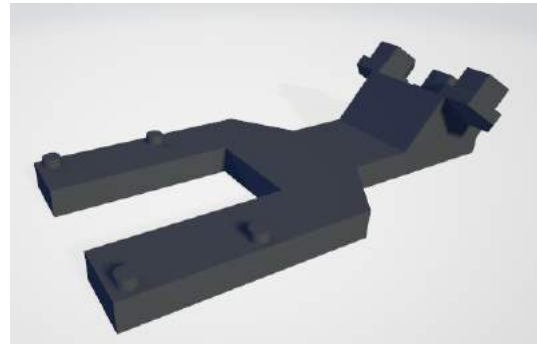

Fig. 4.   3D Model of the cover of the casing

Fig. 5.   3D Model of the camera stand of the casing

B. Obstacle Detection

1) Setting 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]. If the camera has an angle of 50°relative to the horizon and a height of around 1.25 meters then the first row represents the area after 2 meters which was marked by the first horizontal line. The entire height of the frame should measure about 3 meters. The 3-meter mark was based on car sensors which have a 2-2.5 meter range [16]. 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 approximately 1.5 meters 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.
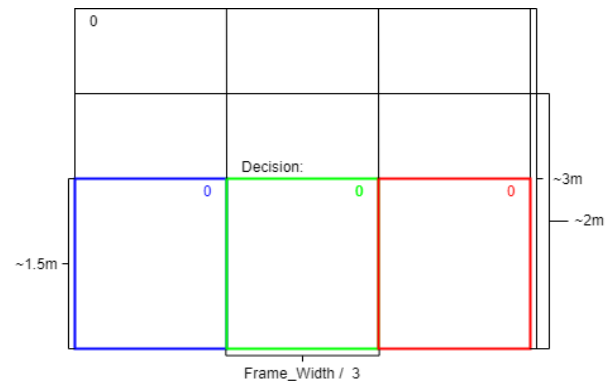

Fig. 6.   The search space

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) Feature Point 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 horizontally to the left if the left buzzer beeps, step horizontally to the right if the right buzzer beeps, and to move forward if both the left and the right beeps. In the case that the whole path is blocked by obstacles, the device will make the user keep moving left or right until an unobstructed path is detected.

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. To measure the performance of the device, nine persons were subjected to three trials. These trials were 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

V. 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).
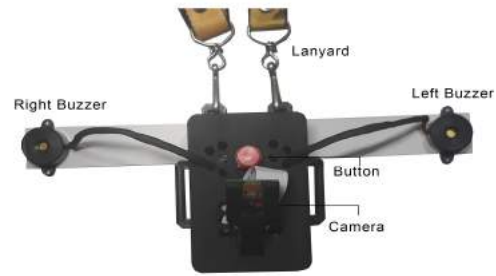

Fig. 8. Completed device

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 image applied the Shi-Tomasi Algorithm unto the grey and blurred image. The bottom right image displayed 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

Appendix I). 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 [17].

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

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

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.

TABLE I

PRECISION TESTING RESULTS

Path Number	Human Found (G)	System Found (D)	G ∩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

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 Appendix II shows the device counting the feature points and flashing the previous decision.

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.

TABLE II

SURVEY QUESTIONS FOR BLINDFOLD ONLY

	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 III

SURVEY QUESTIONS FOR BLINDFOLD WITH CANE/STICK

	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 IV

SURVEY QUESTIONS FOR SYSTEM USE

	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 works.

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.

Figure 12 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
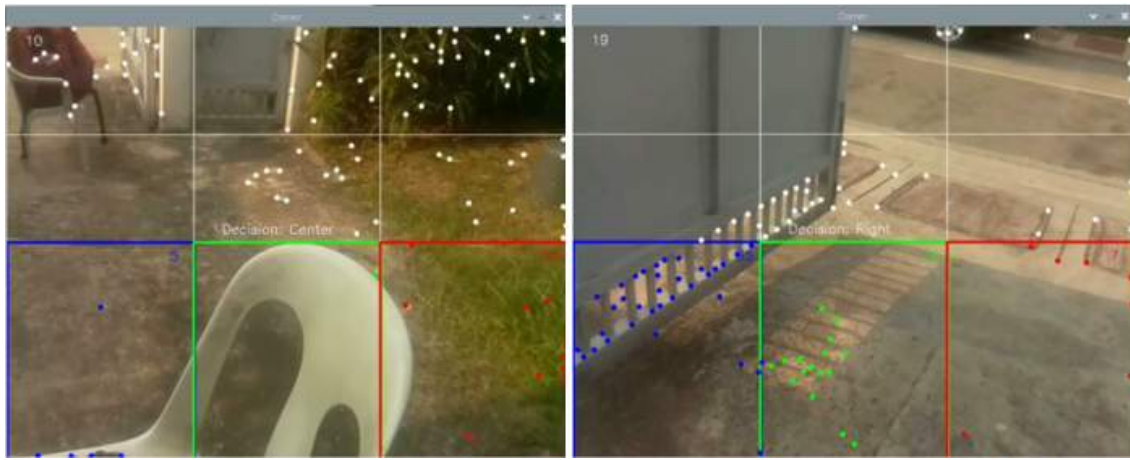
Fig. 11.   Examples of misdetections

TABLE V
USER RATINGS FOR CATEGORY 1

Question	Users' Responses									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

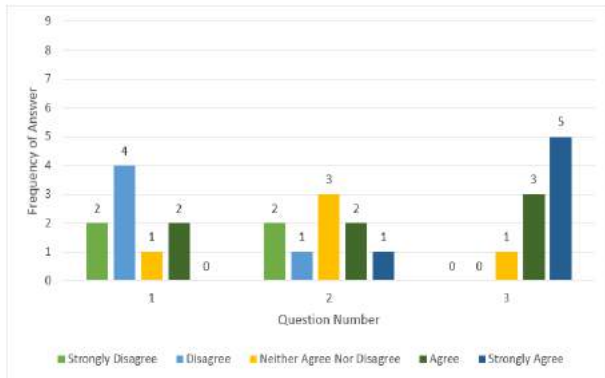third question means that the respondents think that a guide would help them navigate blindly much easier.

Fig. 12.   Frequency of responses for category 1

TABLE VI
USER RATINGS FOR CATEGORY 2

Question	Users' Responses									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

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.

Figure 13 gives the frequency of the answers for category
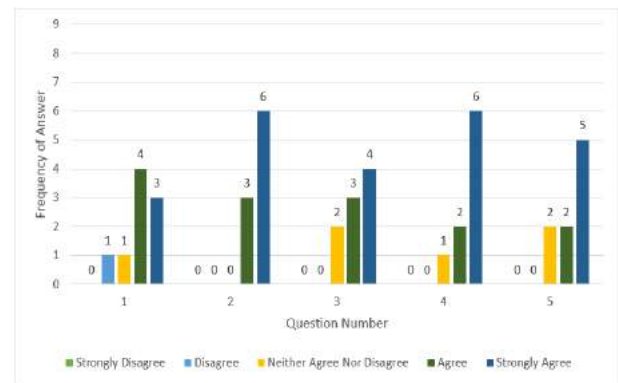

Fig. 13.   Frequency of responses for category 2

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.

TABLE VII
USER RATINGS FOR CATEGORY 3

Question	Users' Responses									Mean
	1	2	3	4	5	6	7	8	9	
Adaptability										
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
Effectiveness										
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
Usefulness										
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
Reliability										
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 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. The questions for this category uses the same 1-5 rating.
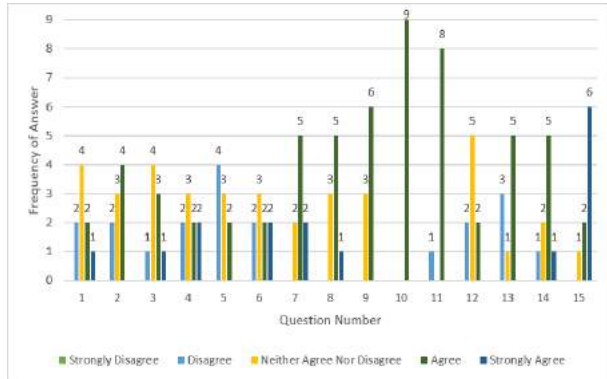

Fig. 14. Frequency of responses for category 3

Figure 14 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.

TABLE VIII

TIME TAKEN TO COMPLETE THE TRIALS

Question	Users' Time Completed									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	27.38
2	28.24	17.21	18.07	17.02	22.90	20.91	36.64	24.22	32.62	24.2
3	36.92	16.95	19.70	18.37	29.33	41.23	40.65	23.00	39.70	29.54

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.

TABLE IX

NUMBER OF MISTAKES MADE PER TRIAL

Question	Users' Mistakes Made									Mean	Mode
	1	2	3	4	5	6	7	8	9		
1	6	3	2	2	4	3	3	2	6	3.44	2, 3
2	2	0	0	0	0	0	0	0	0	0.22	0
3	2	0	0	0	2	2	2	2	1	1.22	2

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.

VI. CONCLUSION AND FUTURE WORK

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.

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 using ultrasonic sensors and a path follower to be able to expand the scope of the environment. A stop function for when users encounter dead-ends or walls will be useful. 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 correct angle.

REFERENCES

[1] Blindness and vision impairment. [Online]. Available: https://www.who.int/news-room/fact-sheets/detail/blindness-and-visual-impairment

[2] J. J. J. B. M. Moreno, S. Shahrabadi and J. Rodrigues, "Realtime local navigation for the blind: Detection of lateral doors and sound interface." 2012.

[3] M. Estremos, "Real-time obstacle detection techniques for forward-located feature-based artificial eye for supporting the mobility of people with visual impairment," 2015.

[4] Vision classifications. [Online]. Available: https://www.teachingvisuallyimpaired.com/vision-classifications.html

[5] M.-N. Chamberlain. Echolocation with the long white cane. [Online]. Available: https://www.nfb.org/images/nfb/publications/fr/fr32/1/fr320104.htm

[6] How do i learn to use a cane? [Online]. Available: https://www.visionaware.org/info/everyday-living/essential-skills/an-introduction-to-orientation-and-mobility-skills/how-do-i-learn-to-use-a-cane/1235

[7] L. B. B.W. Knol, C. Roozendaal and J. Bouw, "The suitability of dogs as guide dogs for the blind: Criteria and testing procedures." 1988.

[8] A. Hutchinson. Bat man. [Online]. Available: https://www.uwo.ca/bmi/news/bmi_news/bat_man.html

[9] D. Jacobson, "Navigation for the visually handicapped: Going beyond tactile cartography." p. 31, January 1994.

[10] M. F. M. Bousbia-Salah and R. Hamdi, "A navigation system for blind pedestrians," 2005.

[11] K. D. J. Ceclio and P. Furtado, "Blindedroid: An information tracking system for real-time guiding of blind people." 2015.

[12] M. F. M. Bousbia-Salah, A. Redjati and M. Bettayeb, "An ultrasonic navigation system for blind people." 2007.

[13] A. C. B. Siddhartha and B. Uma, "An electronic smart jacket for the navigation of visually impaired society." 2018.

[14] Fundamentals of features and corners. [Online]. Available: https://aishack.in/tutorials/shitomasi-corner-detector/

[15] Harris corner detection and shi-tomasi corner detection. [Online]. Available: https://medium.com/pixel-wise/detect-those-corners-aba0f034078b

[16] An introduction to ultrasonic sensors for vehicle parking. [Online]. Available: http://www.newelectronics.co.uk/electronics-technology/an-introduction-to-ultrasonic-sensors-for-vehicle-parking/24966/

[17] T. S. B. Lamiroy, "Computing precision and recall with missing or uncertain ground truth," 2013.

Fig. 15.   Path 1

Fig. 16.   Path 2

Fig. 17.   Path 3

Fig. 18.   Path 4

Fig. 19.   Path 5

Fig. 20.   Path 6

Fig. 21.   Path 7

Fig. 22.   Path 8

Fig. 23.   Path 9

Fig. 24.   Path 10

APPENDIX II
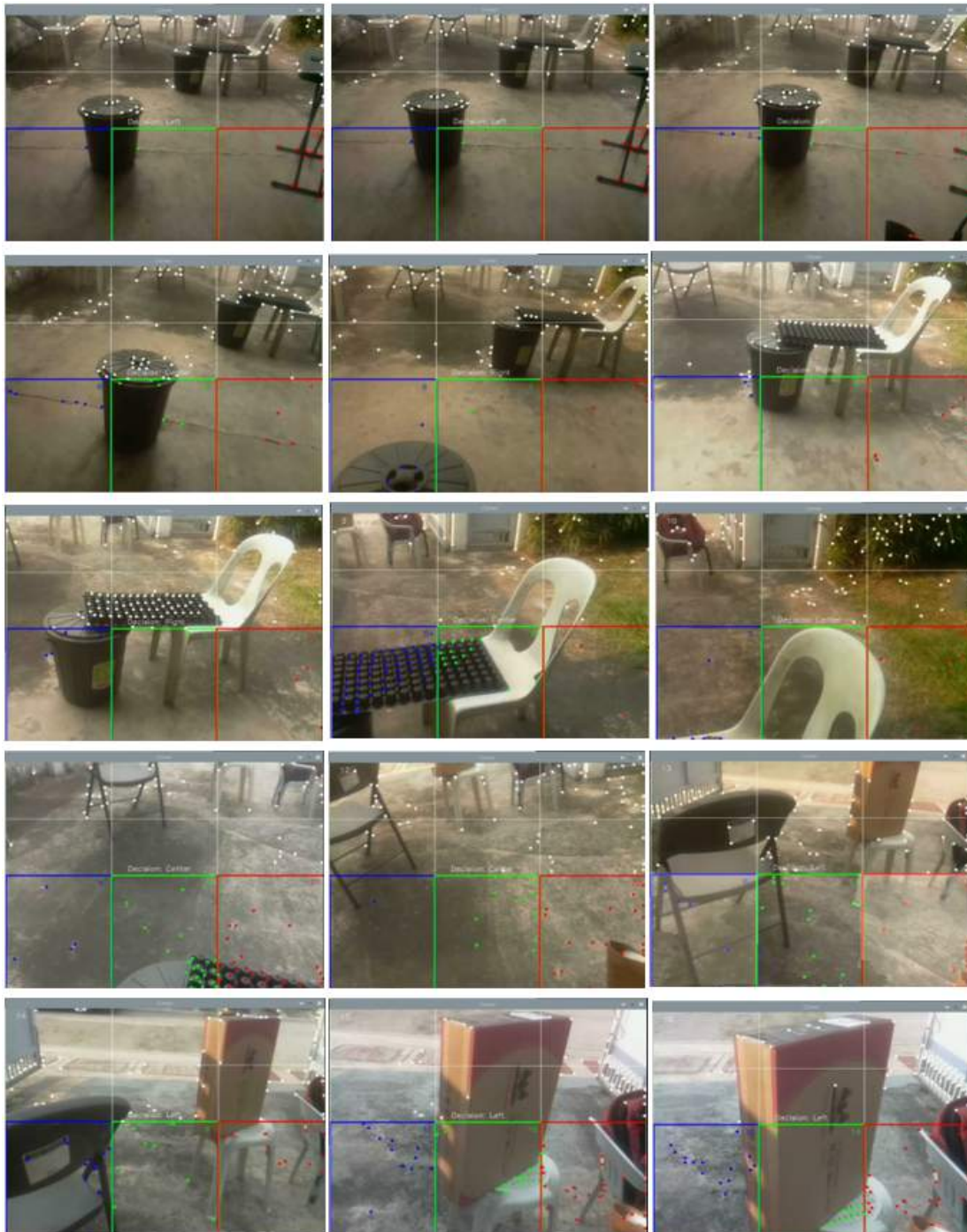SEQUENCE OF FRAMES SHOWING THE TRACKING OF FEATURE POINTS

Fig. 25.   Sequence of frames showing the tracking of feature points