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Development of a Mobile Robot with Camera-based Target Tracking and Obstacle Avoidance Systems

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Abstract: This work describes the preliminary design and development of a mobile robot called CREC (Camera-Based Mobile Robot for Elderly Care). The robot uses a low-cost HC-SR04 ultrasonic sensor to avoid obstacle, and a Pixy CMUcam5 camera as the vision-based sensor to track the target. This camera uses colour marker tag to follow and monitor the target. CREC uses an Arduino UNO microcontroller to fuse data conveyed by the ultrasonic sensor and camera so that the robot can follow the target and avoid obstacles simultaneously. In this work, the hardware design of CREC is described. Furthermore, preliminary experiments to characterize the ultrasonic sensor and Pixy camera are demonstrated to verify the usefulness of the selected sensors for the mobile robot.

Keywords: Mobile robot, pixy camera, target tracking, obstacle avoidance

1. Introduction

Nowadays, elderly care are progressively becoming important and caregiving methods for elderly are also gradually changes along the problems concerned during the caregiving [1]. Basically, living with children or hiring caregivers at home are the methods of conventional elderly care. However, the children may not be at home 24 hours a day and hiring caregivers are costly. Therefore, there have been various initiatives in developing and promoting assistive healthcare systems such as an elderly monitoring system using robots [2].

Implementation of robotic technology is becoming an important research topic in various fields and applications especially in elderly care [3, 4]. Although robots are still unable to replace human caregivers, they can be useful support tool. For instance, in the condition where elderly living independently, they are exposed to dangerous situations such as fall hazards and even depressions which can lead to life-threatening situation. Therefore, it is necessary to have a system that can provide real-time monitoring or prompt notification solutions to inform caregivers or families on the well-being of elderly.

Some companies had introduced elderly people monitoring and notification systems using home appliances such as hot water pot [5], house security alarm [6] and even electricity monitoring [7]. However, such systems have several

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drawbacks for example the inability to detect falls or recognizing the elderly's body and facial expressions in real-time [5, 6]. Additionally, the utilization of multiple static cameras at home to monitor elderly are costly. While wearable devices such as smart watch and smart belt that has the ability to detect sudden abnormal falls are useful innovations, but can be uncomfortable to be worn on a daily basis.

Another method that can be used for elderly monitoring is utilizing robotic technology. Commercially available robotic vacuum robots have been used at homes for floor cleaning [8]. Pet robots are also being used at homes as companions [9]. It is reported that robotic therapy is effective in decreasing stress and anxiety among elderly [4] However, there are various technological challenges in the development of monitoring system using robots.

Two main problems in designing a human monitoring mobile robot are the robot ability to follow the target (humans) and the capability of avoiding incoming obstacles at the same time [5, 6]. Various studies have been carried out to improve robots' ability to follow the target and avoid obstacle simultaneously. These studies involve improving input resolution accuracy, upgrading object recognition via sensors, speed adjustment and detection, and upgrading robot's design and simplify implementation. However, majority of these improvement and upgrading processes involve complex methods and expensive upgrade costs.

This article describes the development of CREC (Camera-based Mobile Robot for Elderly Care), an integrated robotic system consists of human following robotic system and obstacle avoidance system using low-cost components, a continuity of the work done in [10]. In this work, the design of CREC is described in detail and preliminary experiments to verify the usefulness of the robot are demonstrated.

The rest sections of the study are organized as follows: In Section 2, the design of the system including the prototype, vision based tracking system and obstacle avoidance are described. After that, Section 3 describes the preliminary experimental results. Finally, the conclusion points are indicated in Section 4.

2. System Design

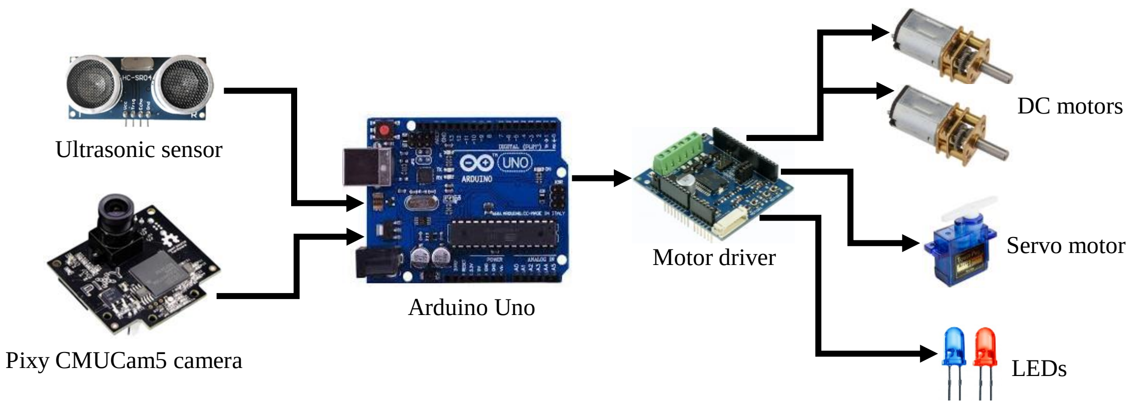


Fig - 1 CREC system overview

2.1 System Overview

Figure 1 shows the block diagram of the proposed mobile robot CREC. The input components are consist of a HC-SR04 ultrasonic sensor as main component for obstacle avoidance system, and a Pixy CMUcam5 camera as main component for human target following system. Both components are connected to an Arduino Uno microcontroller. The output components are consist of two (2) DC motors for the movement of robot and a servo motor attached with ultrasonic sensor that can perform pan movement to search for target object. These motors are controlled by an L293D motor driver shield. Furthermore, two (2) LEDs are used to indicate the presence of obstacle on the left and right sides. Figure 2 shows various views of the actual CREC taken from the front, side and top view respectively.

2.2 Prototype Design

As shown in Figure 2, there are four (4) main components in CREC which are Arduino Uno microcontroller, a Pixy camera as vision-based input component, an ultrasonic sensor as obstacle avoidance input component and DC motors as output component. A Pixy CMUcam5 camera is positioned on top of CREC that can pan to the right and left. The camera tracks the target based on a colour marker and sent appropriate data to Arduino. The camera uses Serial Peripheral Interface bus (SPI) to communicate with Arduino and motor driver.

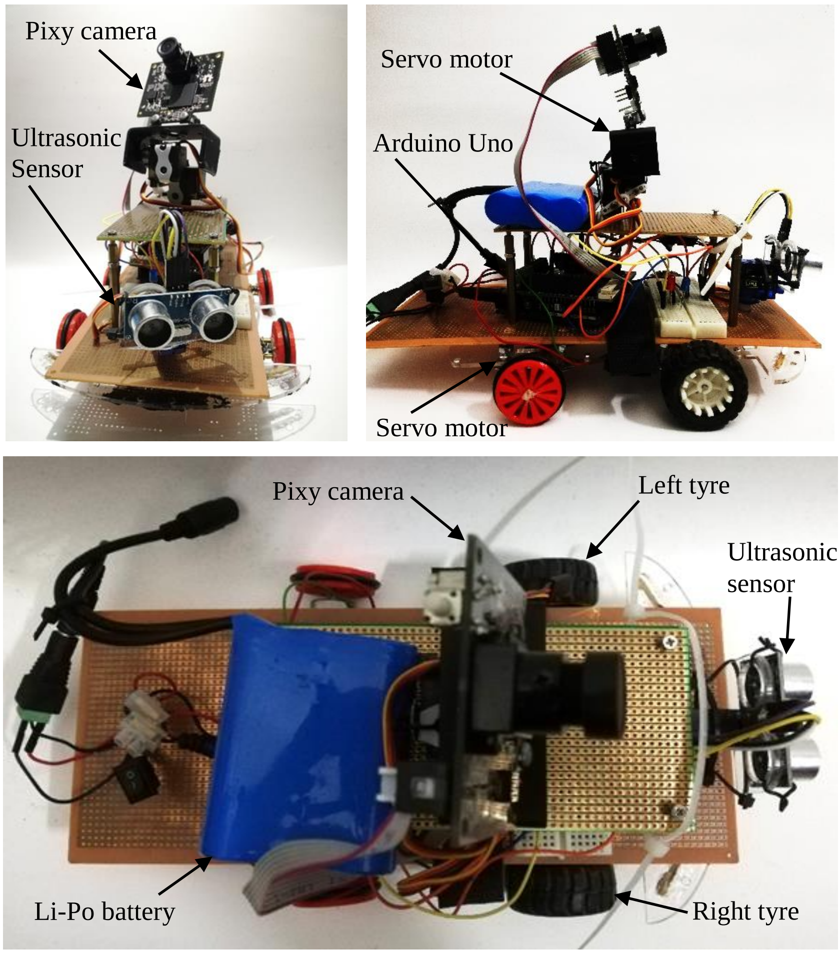


Fig - 2 Various views of CREC

2.3 Vision Based Target Tracking

In this system, the vision-based sensor for target tracking is the Pixy CMUcam5 camera. The camera uses a hue-based colour filtering algorithm to detect objects. The target is called as signature, where basically, 7 different colour signatures can be set using PixyMon software as shown in Figure 3. After a signature has been set, Pixy camera starts to calculate the initial area using the width and height of signature's block, and the location of the center of the detected target on *x*- and *y*-axes. These information are used to control the movement of CREC.

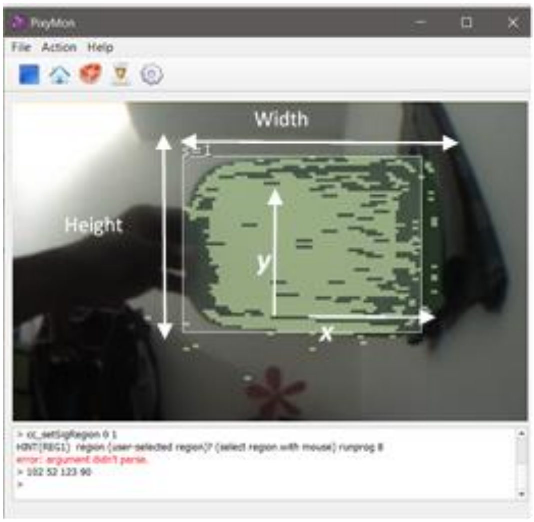


Fig. 3 - Signature setting using PixyMon software

The robot's motor movements are based on the distance with the object tracked calculated from the images taken by the Pixy camera. The movement of CREC correspond to the conditions in the signature *if-loop* (for example *if* (signature == 2)), where the Pixy camera calculate the *newArea* of signature's block and compare it to the initially calculated area. If (signature == 2) is false, the robot will stop and start scanning for signature again.

To follow a target, the robot is programmed with an algorithm consists of camera image parameters of width, height, x-axis and y-axis of the object tracked by the camera. The movement of the robot responded to the changes of the size and position of the signature from the initial area and position. After setting the colour signature, the camera calculates the target initial area within the first 5 sec based on the Equation (1) as follows

$$area = width * height. \tag{1}$$

Then, the initial area is set with range minimum and maximum of ±1000 as follows

$$maxArea = area + 1000, \tag{2}$$
$$minArea = area - 1000. \tag{3}$$

When the target moves forward, the signature become smaller and *newArea* is calculated using the following equation

$$newArea = width * height. \tag{4}$$

Pixy cam then compares the value of *newArea* with the initial area values *maxArea* and *minArea*. When the size of $newArea < minArea$, the mobile robot will respond and move forward. In other word, if the target moves backward, the signature area size becomes smaller compared to the initial area, thus, forward command is given to the robot. On the other hand, if the size of $newArea > minArea$, this means that the new signature area size becomes larger than initial area size, thus, robot will respond and moves backward. The min value of x is set to X_{min} = 70 and max value set to X_{max} = 200. If the signature is within the range of minimum and maximum value of x, the mobile robot continues moving forward. On the other hand, the robot turns to the left when $x < X_{min}$, and when $x > X_{max}$, the mobile robot turns to the right. The mobile robot stops if the area and position of the signature is the same with initial value and also when no signature colour is detected. Table 1 shows the movement of the right and left motors corresponding to the given command. Pulse Width Modulation (PWM) of the motors determined the direction and speed where +70 PWM move the motor forward with a speed of 70 PWM, and -70 PWM move the motor backward.

Table 1 - Command and robot movement

Command	Right Motor (PWM)	Left Motor (PWM)
FORWARD	-70	70
BACKWARD	70	-70
TURN RIGHT	70	70
TURN LEFT	-70	-70
STOP	0	0

2.4 Obstacle Avoidance System

As shown previously in Figure 2, a HC-SR04 ultrasonic sensor is positioned at the front of the robot to detect obstacles. Basically, the sensor emits an ultrasound at 40 kHz which travels through the air and if there is an object or obstacle on its path it will bounce back to the module. Distance can be calculated by considering the travelling time and the speed of the sound. Trigger pin is set on a high start for 10 us in order to generate the ultrasound. That will send out an eight (8) cycle sonic bursts which will travel at the speed of sound, and it will be received in the echo pin. The echo pin will output the time in microseconds the sound wave travel. Then, Arduino sends data to motor driver and controls the DC motors according to the programmed instructions.

Figure 4 shows the algorithm flowchart of the obstacle avoidance system for CREC. The system starts with adjusting the servo motor's alignment stacked with ultrasonic sensor to 90°. The system immediately search for any obstacle within 30 cm range by executing *Search*() function. CREC moves forward if there is no obstacle detected in front of it. In a scenario where there are obstacles detected, CREC stops and executes *ChangePath*() function. Servo motor rotates 170° to capture the distance on the right side, and then rotates 12° to the left.

After acquiring the distances of the right and left sides, the system compares both distances to decide the best path to be taken. A simple *if-else* loop is used in the source code to determine the path by comparing both distances. If the distance on the right is greater than the left, the system recognizes an obstacle on the left side, and the decision is to turn to right, then moves forward. The code repeats until it detects any further obstacle. The distance set between mobile robot and obstacle is 30 cm before triggering the avoid action. When obstacle is within the range of detection, the mobile robot stops and search for possible path to avoid obstacle. The ultrasonic sensor stacked on the servo motor rotates to the right and left to search a path. After a path with no obstacle within range is detected, the mobile robot turns and moves forward avoiding the obstacle.

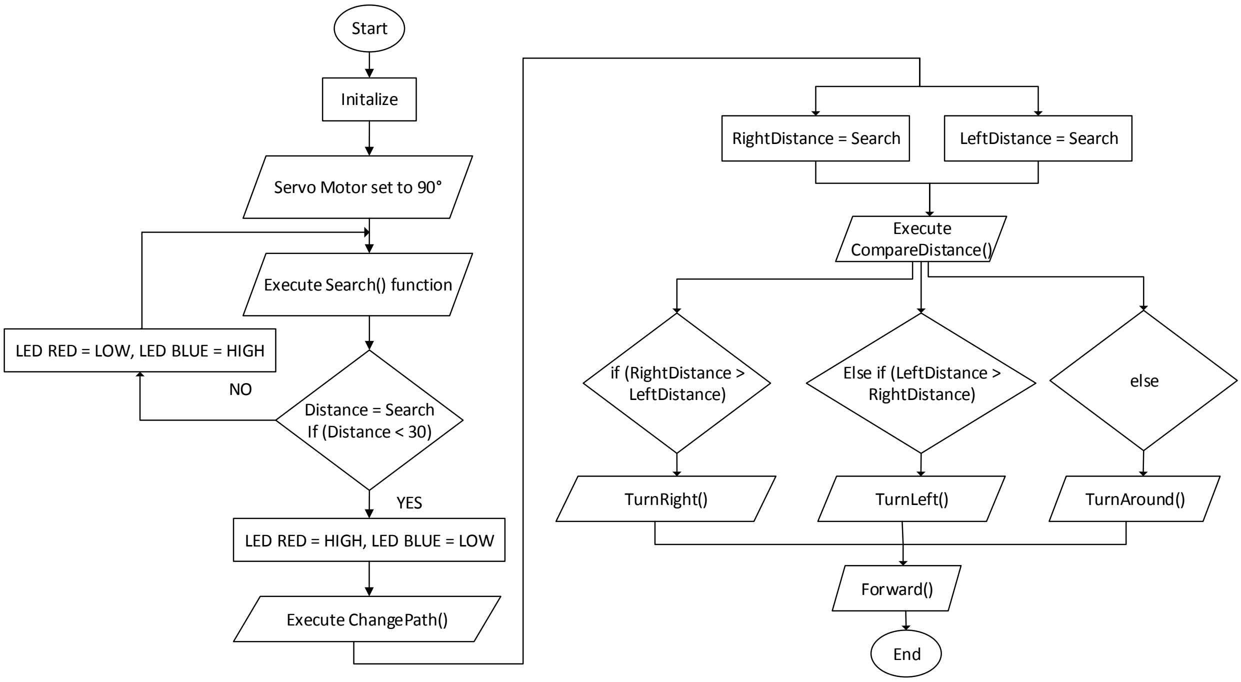
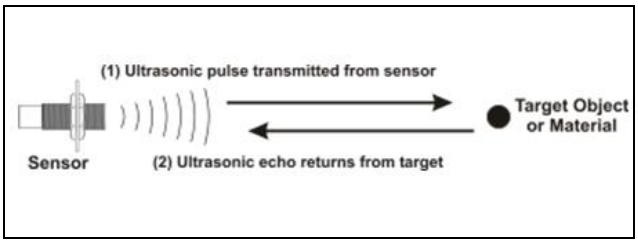


Fig - 4 Flowchart of the algorithm for CREC obstacle avoidance system.

3. Experiments and Results

3.1 Experimenting the Ultrasonic Sensor



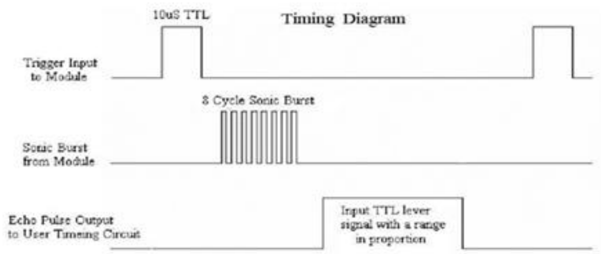


Fig. 5 - Ultrasonic sensor working principle.

Fig. 6 - Timing diagram of ultrasonic sensor.

Figure 5 illustrates the working principle of ultrasonic sensor. As shown in the figure, the ultrasonic pulse is transmitted from sensor to a target object or material. Then, the ultrasonic echo returns from the target towards the sensor. Figure 6 shows timing diagram of ultrasonic sensor. In order to generate the ultrasound, the sensor trigger needs to be set on a high state for 10 µs. That will send out an 8 cycle sonic burst, which travels at the speed of sound and it will be received in the echo pin. The echo pin will output the time in microseconds.

For example, if the object is 10 cm away from the sensor, and the speed of the sound is 340 m/s or 0.034 cm/µs the sound wave will need to travel about 294 µs. The echo pin will be double that number because the sound wave needs to travel forward and bounce backward. So, in order to get the distance in cm, the received travel time value needs to be multiplied from the echo pin by 0.034 and divide it by 2. Below are the calculation for the time taken to detect an object 10 cm away:

$$\text{Sound of Speed, } v = 340\text{m/s} = 0.034\text{cm/s}, \quad (5)$$

$$\text{Time} = \text{Distance/Speed} = s / v = 10 / 0.034 = 294\mu\text{s} \quad (6)$$

$$\text{Distance, } s = t * 0.034 / 2. \quad (7)$$

Experimental setup. The HC-SR04 Ultrasonic Module has 4 pins, Ground, VCC, Trigger and Echo. The Ground and the VCC pins of the module needs to be connected to the Ground and the 5 V pins on the Arduino Board respectively and the trig and echo pins to any Digital I/O pin on the Arduino Board. Figure 7 shows the connection of ultrasonic sensor to Arduino Uno, where the trigger and echo pins are connected to digital pin 8 and pin 7 respectively. A simple test has been conducted to demonstrate the working principle of HC-SR04 Ultrasonic sensor.

Experimental steps. This experiment was conducted to validate the performance of the sensor in measuring distance between the sensor and target. The experiment steps are as follows. First, the circuit was placed on a flat surface to avoid misalign of the pulse transmitted to the target. Then, a smooth and flat surface of the target was used to get clear returning echo from the target. The distances between sensor and target were measured in three (3) cases: 10cm, 20cm and 30cm. Finally, the data then plotted on graph.

Experimental results. Figure 8 shows the results for the three (3) cases. Each case was experimented for five (5) times and the average values for each case were calculated and graph are plotted as shown in Figure 9. The figure represents the average data of traveling time for distances of 10 cm, 20 cm and 30 cm respectively. Table 2 shows the average data of traveling time for distance. Based on Figure 9, it is clearly shows the accuracy of the sensor is good as the distance from the object is maintained within 1 cm to 2 cm range and do not fluctuate too much.

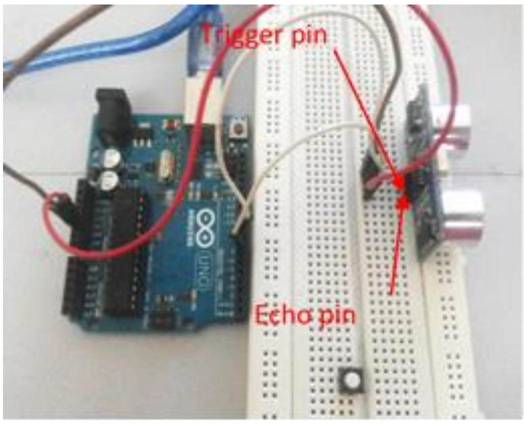


Fig. 7 - Experimntal setup for experiment on ultrasonic sensor

(a)
(b)
(c)

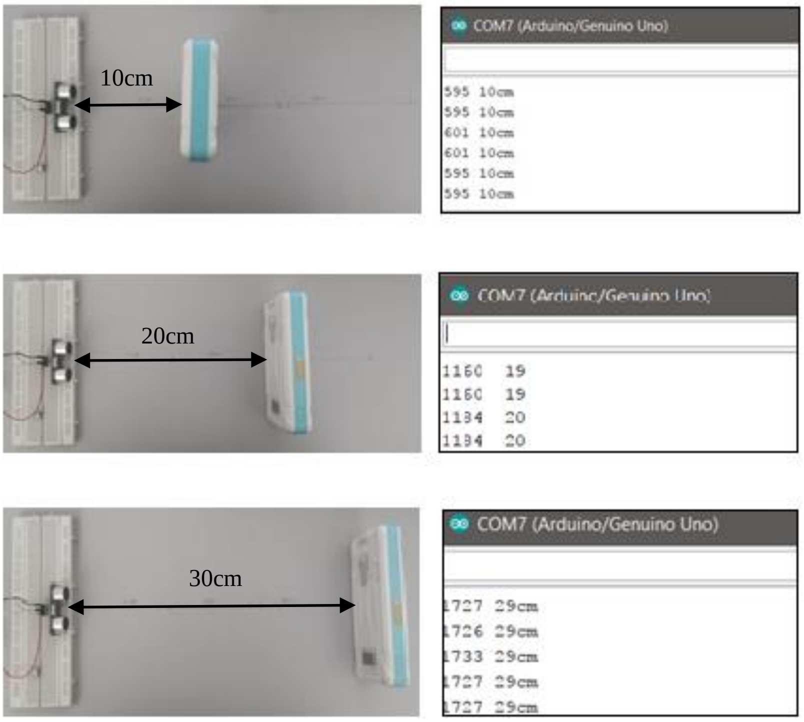


Fig. 8 - Experiment setup (left images) and results (right images) for three cases. The distances between sensor and target at (a) 10 cm, (b) 20 cm and (c) 30 cm

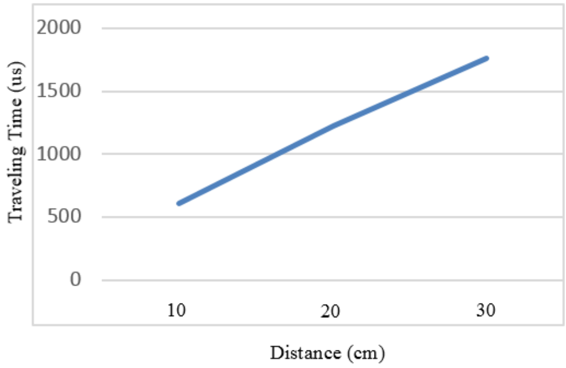


Fig. 9 - Result of travelling time against distance

Table 2 - Average duration vs distance

Travelling Time. (us)	Distance(cm)
605	10
1221	20
1760	30

3.2 Optimizing PixyCam

The objective of this experiment is to optimize the setting for PixyCam to be able to track the object smoothly. This was done by setting the signature and pan/tilt demonstration. Pan/tilt is to move the PixyCam after it detects the object and after setting the signature of the tracked object. Figure 10(a) shows the setting for pan/tilt demonstration that can be found in the Action tab. After selecting Pan/Tilt demo, the camera is ready to track the object with signature 1. Figure 10(b) shows several tracked signatures appear, somewhat like noises. This is because the signature been set (s=1) did not optimized completely. This will reduce the efficiency of the camera to track the object smoothly. To overcome this problem, pan/tilt gains need to be modified. Figure 10(c) shows the parameters of pan/tilt can be modified by changing the gain of parameters by increasing or decreasing the values to modify pan/tilt sensitiveness. For example, changing Pan P gain from 350 to 50 will cause it to pan more slowly.

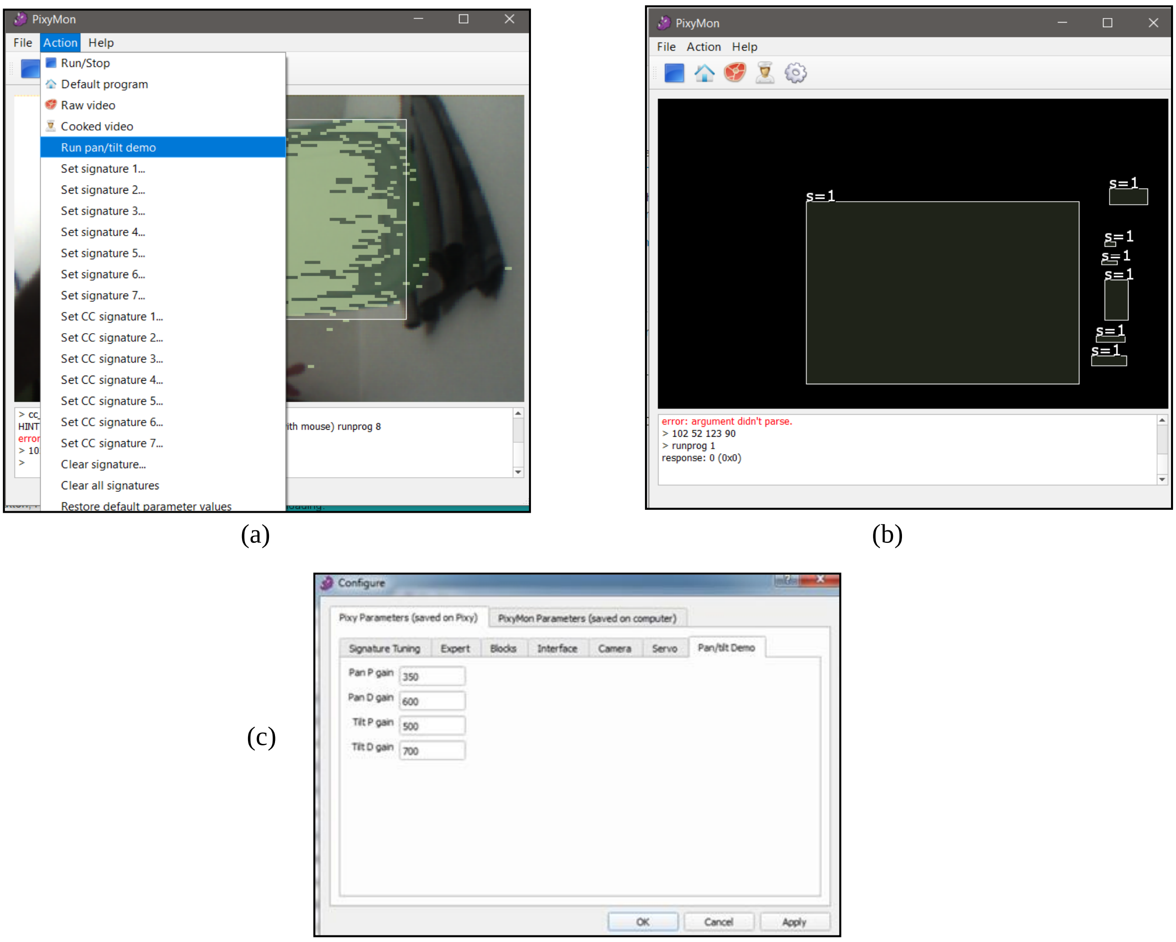


Fig. 10 - (a) Setting a signature; (b) Tracking a signature in Pixy cam; (c) Pan/tilt demo parameters

3.3 Obstacle Avoidance Experiments

The objective of this test is to verify the functionality and accuracy of the developed obstacle avoidance system through two cases in actual environment: (a) avoiding an obstacle, and (b) avoiding multiple obstacles in a maze environment.

(a) Experiment Case 1: Avoid an obstacle

This experiment was carried out to analyze the accuracy of robot movement corresponding to the distance detected by the ultrasonic sensor. The experiment setup is shown in Figure 11. The experiment steps are as follows. A single obstacle was placed in front of robot with the initial distance between the robot and obstacle was to 35 cm. The distance data was observed and recorded. Then, the distance between the robot and obstacle was changed to 15 cm. Again, the distance data was observed and recorded.

Experimental results and discussion. Figure 11(a) shows the distance between robot and obstacle exactly at 35 cm and the ultrasonic sensor face at 90 degree of servo motor. The Blue LED light up if there was no obstacle in range of 30 cm. When an obstacle detected within the range of 30 cm the program sequentially executed *Search*(), *CompareDistance*() and *ChangePath*() instructions to avoid obstacle. Red LED turned ON. Figure 11(b) shows the ultrasonic sensor rotated 80 degree to the right precisely at 170° and then ping the distance on the right side for 1 second, then rotated to the left side precisely at 12° as shown in Figure 11(c), and ping the distance for 1 second. The source code command *CompareDistance*() compares the distance for both side to execute the *ChangePath*() command.

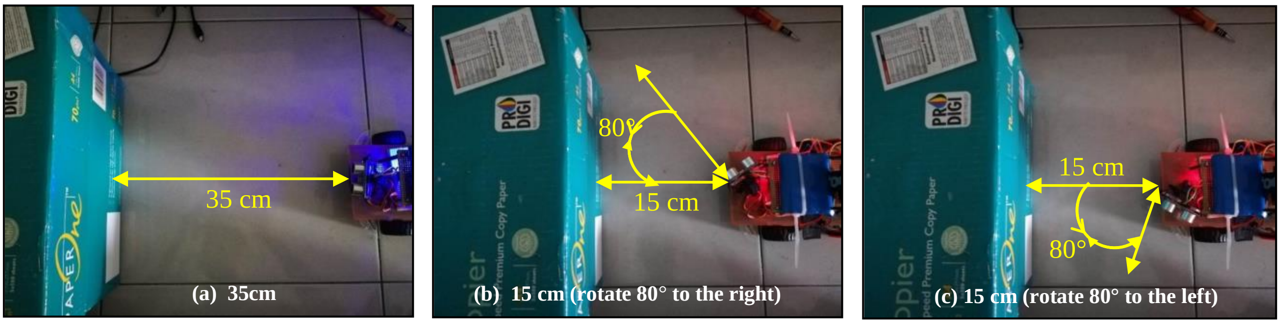
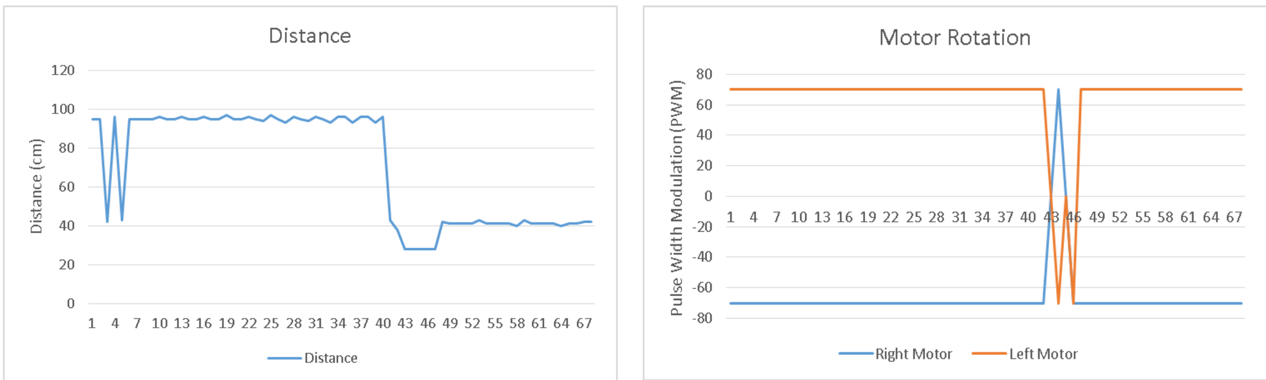


Fig. 11 - Distance between robot and obstacle

The results are shown in Figure 12(a) and Figure 12(b) for distance detected by ultrasonic sensor over time and motor rotation respectively. Based on the figures, the accuracy of the mobile robot movement and also the efficiency of ultrasonic sensor can be observed. In Figure 12(a), at readings 3 and 5, the distance detected by ultrasonic sensor was 42 cm and 43 cm respectively, whereas the other reading maintained at ±90 cm. When compared with the values in Table 2 from the validation experiment, there was no fluctuation in the readings. It shows that the performance of ultrasonic sensor may decreases when connected with other components.



(a) (b)

Fig. 12 - (a) Distance detected by ultrasonic sensor over time; (b) Motors rotation PWM

The mobile robot moved forward when the distance to the obstacle was more than 30 cm. From the Figure 12(b), the PWM of right motor is -70 and left motor is 70, proving that the robot was moving forward which correspond to Table 2. At reading 44 of Figure 12(b), the distance between mobile robot and the obstacle was 28 cm that is less than 30 cm. This shows that the PWM for both motor is 0 as the mobile robot stopped moving. Then, the right motor and left motor produced PWM values 70 and -70 respectively to move the robot backward. Then, the sensor performed

Search() instruction to decide which path to take. As a result, at reading 46 both motor PWM is 170 resulting to the mobile robot to turn to the left. The result demonstrated the accuracy of motor movement when avoiding an obstacle.

(a) Experiment Case 2: Avoid multiple obstacles

For this experiment, the objective was to proof the effectiveness of the developed algorithm in avoiding multiple obstacles along the path. From the experiment, the ability of the robot to move from point A to point B in a structured maze was analyzed. The sole purpose of this test was to analyze the accuracy and the efficiency of the algorithm in Table 3 to solve the maze. Figure 13 shows the experimental setup where the mobile robot was placed in a simple maze. Figures 14 and 15 shows the results for distance detected and motor rotation respectively.

Experimental results and discussion. In Figure 14, readings at 37, 45, 115 and 285 shows abnormal distance measurements by the sensor with 638 cm, 698 cm, 407 cm, and 370 cm were measured, respectively. The normal distances detected are within 90 cm and 100 cm and again this can be said that the performance of ultrasonic sensor may decreases when multiple components assembled. Corresponding to Figure 14, the motor rotation results shown in Figure 15 shows unsatisfied expected outcome where the mobile robot failed to solve the maze. From Figure 15, it is found that the measurement at 57 is precisely at t = 49 s, the repetitive action of the mobile robot to turn left to second part of the maze. After a while, the mobile robot success to turn to second part of the maze at t = 120 s but has a hard time again to turn left and stuck at reading 253.

Several conclusions for the test can be made. The condition for distance to detect obstacle is not suitable to be set at 30 cm. It is because the distance is quite far and not suitable in narrow environment. There might be a situation when a house is in mess with more obstacle, thus, a shorter range is better. Furthermore, the mobile robot is too heavy causing the motors had difficulties to correct movement direction.

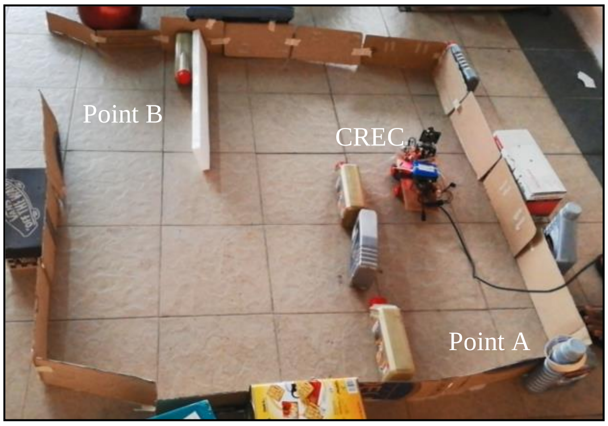


Fig. 13 - Experimental setup

Table 3 - Robot movement correspond to distance

Distance (cm)	Robot Movement
Distance < 30)	ChangePath ();
(Distance >= 30) && (Distance < 60)	Forward ();
(Distance >= 60) && (Distance < 90)	Forward ();
else;	Forward ();

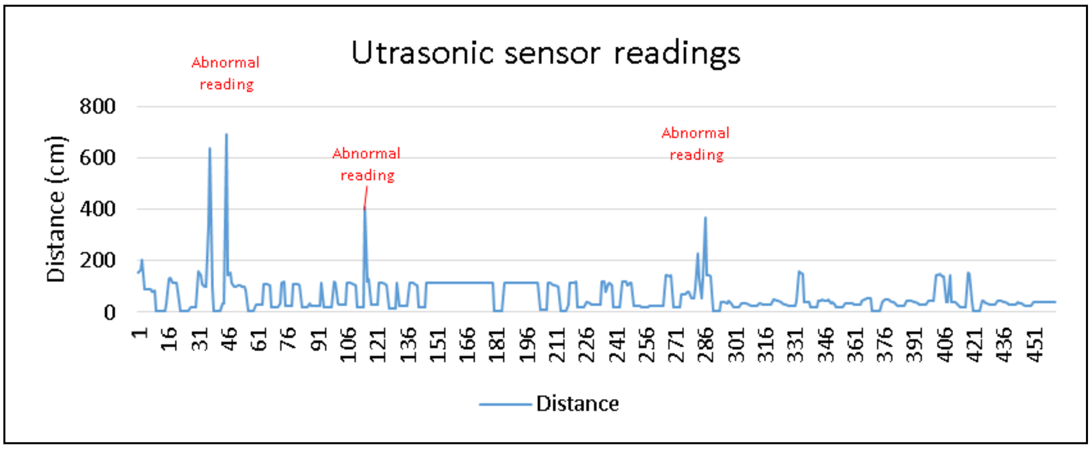


Fig. 14 - Distance detected by sensor

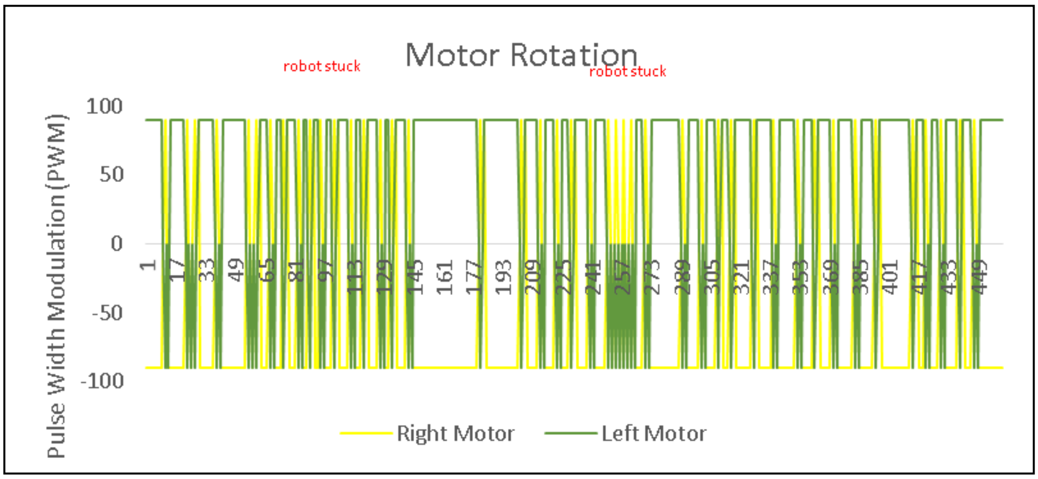


Fig. 15 - Motor movement corresponding to sensor

4. Conclusion

In this work, the hardware design of CREC has been described. Several preliminary experiments have been done to analyse sensors accuracy and efficiency to perform tasks. For obstacle avoidance system, the characteristics of the ultrasonic sensor to measure the distance between robot and target have been analysed. The results show that the sensor was working properly. For obstacle avoidance system, two experimental setup were conducted to test the algorithm implemented to the system and also to verify the performance of the robot in certain environment. First case was to test the basic function and the results proved the accuracy of the motor movement when avoiding an obstacle. Second case was to test the capability of the robot to solve a maze. The results show that improvement must be carried out on the implemented algorithm.

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References

[1] Garcia-Tsao, G.; Abraldes J. G.; Berzigotti, A.; Bosch, J. (2017). Portal hypertensive bleeding in cirrhosis: Risk stratification, diagnosis, and management: 2016 practice guidance by the American Association for the study of liver diseases. Hepatology. 1; 65(1):310-35

[2] Tomoya, A.; Nakayama, S.; Hoshima, A.; Sugaya, M. (2015). A Mobile Robot for Fall Detection for Elderly-Care. KES2015: 870-880

[3] Wada, K. and Shibata, T. (2007). Living With Seal Robots - Its Sociopsychological and Physiological Influences on the Elderly at a Care House, IEEE Transactions on Robotics, Vol. 23 Issue 5, 972-980

[4] Petersen, S.; Houston, S.; Qin, H.; Tague, C. and Studley, J. (2017) The Utilization of Robotic Pets in Dementia Care. Journal of Alzheimer's disease: JAD, 55(2): 569–574

[5] Zojirushi: Mimamori Hotline, http://www. Mimamori.net/service/index.html

[6] Osaka Gas Security Service: Omamori Call, http://www.oss-og.co.jp/service/omamori/index.html

[7] Howz: Intelesant Ltd., https://howz.com/

[8] Adrienne So. The best robot vacuums for every home and budget, https://www.wired.com/gallery/best-robot-vacuums/

[9] Abdi J., Al-Hindawi A., Ng T., & Vizcaychipi M. P. Scoping review on the use of socially assistive robot technology in elderly care. BMJ open, 2018: 8(2), e018815

[10] Jamatolail, M.F.M.; Ambar, R.; Choon, C.C.; Wahab, M.H.A.; Mohd, M.N.H.; Poad, H.M.; Jamil, M.M.A.(2019). CREC: Camera-Based Mobile Robot for Elderly Care. International Journal of Advanced Trends in Computer Science and Engineering, 8(1.4): 51- 56