FINAL REPORT

COST-EFFECTIVE ROTATING INFRA-RED SENSOR FOR ROBOTIC APPLICATIONS

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CERTIFICATION OF APPROVAL

by

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Approved by,

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UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

January 2017

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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ABSTRACT

This project presents the application of low cost infrared sensor for robotic applications. Infrared sensor application is very common in these days and has been utilized in various fields. However, infrared sensors which offer high accuracy and cover wide angle in detection are costly. Thus, the main objective of conducting this project is to design a prototype that can perform a two-dimensional(2D) area mapping of the surrounding to give accurate detection and identification of the surrounding objects by utilizing low-cost infrared sensor, instead of using the high performance infrared sensors which their market prices are much higher. The prototype is designed to have a single rotating infrared sensor installed on the robot`s body, with a particular emphasis on having a wide observation capability up to 180°. By using Arduino as the microcontroller, the prototype aims at providing the robot real-time and reliable information about identification of the shapes of the surrounding as well as the objects within the field of view. The objects used for the identification testing are mostly polygon shapes such as square, rectangle, sphere, cone, and pyramid. When conducting the experiments, the accuracy, limits and sensitivity against known obstacles of the infrared sensor should be considered so that accurate results can be obtained. Testing on the distance measurement of the objects using the infrared sensors have been conducted and the results obtained can be consistent and the accuracy however varies between 1cm to 2cm. Apart from that, the results obtained from the testing on the mapping of the surrounding area have proved that the system works fine on the mapping, however necessary improvements would have to be employed on the accuracy as well as the sensitivity against the objects detected.

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Apart from that, the author would like to express his ultimate gratefulness to his families, who always are the most reliable sources of support, encouragements although they live far from the author. The author felt peace and encouraging every time the author thought of them. They were, are and will be the author's strong inspiration and part of whatever successes the author achieved.

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CHAPTER 1

INTRODUCTION

1.1 Background

Infrared sensor is an electronic equipment mainly used for detecting and sensing particular characteristics of the surrounding by emitting and receiving infrared(IR) radiation. Infrared radiation is an electromagnetic radiation with wavelengths range between 0.75μm and 1000μm, which is invisible to the human eyes. In general, infrared radiation can be classified into near-infrared, mid-infrared and also far-infrared. The wavelength which ranges between 0.75μm to 3μm is referred as the near-infrared whereas the mid-infrared has wavelength ranges from 3μm to 6μm. Infrared which has wavelength greater than 6μm is categorized as the far-infrared. In these day, infrared sensors have been widely used especially for distance measurement purposes, surface feature detection, barcode decoding, as a tracking system and various types of robotic applications. The significant advantages of infrared sensors are their simple circuitry, low power requirements and their portable features.

In general, infrared sensors can be categorized into two main types, that active infrared sensors and passive infrared sensors. For the active type, the sensor comprises of both infrared emitter and detector. This type of infrared sensors works by emitting infrared radiation towards the targets and the reflected energy is then focused onto the detector. The measured data is then processed using various signal-processing algorithms to extract the desired information. Two types of active infrared sensors include the bream beam sensor [Figure 1] and the reflectance sensor [Figure 2]. On the other hand, passive infrared sensor only comprises of the infrared detector and does not include any infrared sources. This type of infrared sensors detects energy emitted by objects in the field of view and may use signal-processing algorithms to extract the desired information.

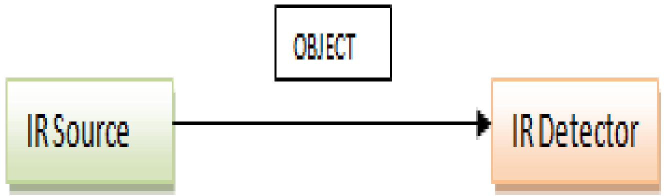


Figure 1 : Break Beam Sensor

Break Beam Sensor works by emitting infrared radiation directly towards the IR detector and the output is generated based on the change in the radiation.

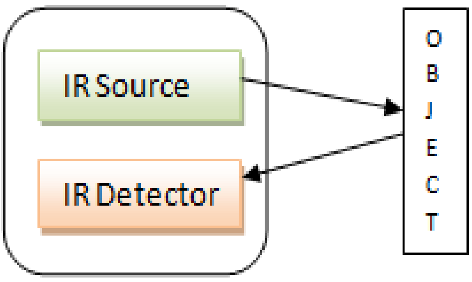


Figure 2 : Reflectance Sensor

Reflectance Sensor operates by sending infrared radiation from the IR emitter towards the object in which the radiation is then reflected back by the object into the IR detector. The properties of the object can then be figured out based on the change in the amount of received IR radiation.

1.2 Problem Statements

Infrared(IR) sensors are used in varied applications such as robotics, autonomous or self-driving cars and drones to detect objects in advance. However, accurate IR sensors are very expensive, particularly for a rapid prototyping environment where sensing systems can be disposable, need to be developed quickly and in a cost-effective manner.

In addition, infrared sensors applications often require simultaneous 360° detection of objects. Although rotating IR sensor can increase the angle covered in detection by using a single sensor, the detection ability is limited by the scan rate and rotation speed of the sensor base. The mechanical rotating platform also introduces an extra subsystem to maintain which increases cost.

Therefore, there is a need to develop a cost-effective rotating IR sensor for robotics that is able to detect objects within a circular range with acceptable range and accuracy

1.3 Objectives and Scope of Study

The main purposes of conducting this study are :

1. To develop a rotating IR sensor that can detect objects within a circular region
2. To test the performance of the infrared sensor in terms of its accuracy, limits and sensitivity against known obstacles
3. To design a prototype that can perform area mapping and identify the shape of the surrounding as well as the obstacles by using infrared sensor and microcontroller Arduino

The first and foremost scope of study for this project is to deal with the infrared sensors and also the servo motors. Infrared sensors act as the main sensing and detecting tools in this project and with the help of the servo motors, the sensors would have to be able to detect objects within a 2D circular region. The minimum distance from the infrared sensors to the object is set into 15 cm and the furthest up to 150cm. After sensing the existence of the objects, the readings would have to be sent to the microcontroller so that the shapes of each of the objects can be identified and be displayed to the user. The accuracy, sensitivity and limitations of the infrared sensors used have to be considered to make sure accurate and reliable results can be obtained during the experiments.

The second scope of study is to use Arduino as the microcontroller for this project. Arduino Mega is programmed to be able to perform a 2D mapping of the surrounding area and hence conduct the identification of the shape of the obstacles within the area. The scan rate and rotation speed of the infrared sensors should also be manipulated by the Arduino.

CHAPTER 2

LITERATURE REVIEW AND THEORY

2.1 Comparison of the Infrared Sensor System Design

In the research paper “Infrared Sensor Rig in Detecting Various Object Shapes”, infrared sensors are used to measure the distance of the objects and to identify shapes of different objects. Five Sharp GP2D120XJ00F infrared sensors are placed on the inner edges of a pentagonal rig and an object is located at the center of the sensor rig [Figure 3]. Arduino is used as a microcontroller to control the rotation of the sensor rig. One rotation covers up to 72°, thus five rotations cover a full 360°. A control circuit is designed to control the ON and OFF switch of the infrared sensors. This is because when all the sensors are turned ON at the same time, the possibility of errors occur is high. Data received by the sensor rig is delivered to the microcontroller and post processing of the data is fully run using the Matlab software to reconstruct the image from the data obtained by infrared sensor.

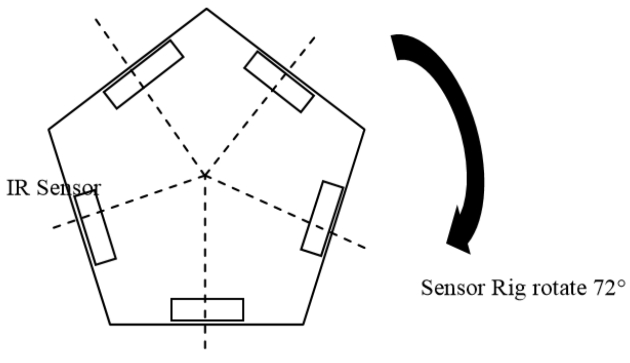


Figure 3 : Arrangement of Sensor Rig and Infrared Sensors Position[1]

Although this paper implemented infrared sensors to identify the shapes of detected objects accurately, the system does not have the capability to scan the surrounding objects in which the effective scanning area is only within the sensor rig.

On the other hand, in the research paper “Low-Cost Dual Rotating Infrared Sensor for Mobile Robot Swarm Application”, infrared sensors are used to identify neighboring robots from objects and their position. Two Sharp GP2Y0A02YK infrared sensors and four MiniStudio MiniS RB90 servo motors are used. Each infrared sensor is connected to two servo motors, the upper motor and base motor [Figure 4]. The base motor rotates 180° and the upper motor adds another 60° [Figure 5]. The remaining 120° range cannot be observed, since the line-of-sight path is blocked by the housing, but is covered by the another infrared sensor that scans the same range in the opposite direction. Therefore, a pair of infrared sensors can cover a full 360°.

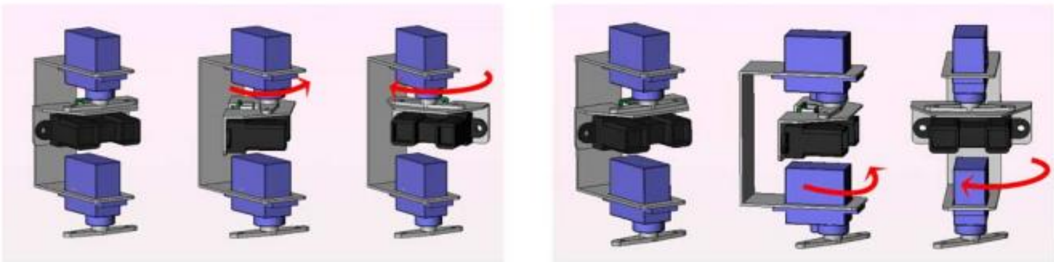


Figure 4 : Rotation of the Upper and Lower Motors[1]

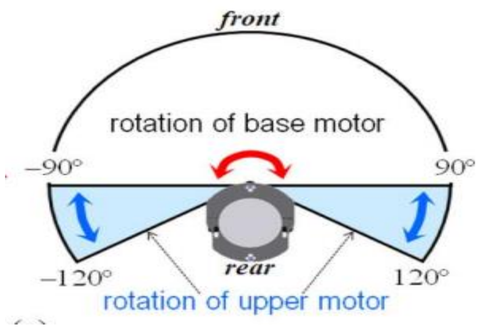


Figure 5 : Scanning Function[1]

Although the scanning function is useful in detecting the presence of other robots, the power consumption may be high since two servo motors are used to control a single infrared sensor in which there are two infrared sensors required to be controlled.

2.2 Comparison of the Infrared Sensors

Infrared Sensor	Advantages	Weaknesses
Hokuyo PBS-03JN Scanning Infrared LED Obstacle Detection Sensor	- contains a mechanically rotating LED that generates infrared radiation - scans at 1 rev/100msec - usable scan that covers a 178.2° arc (angular resolution of 1.8°) - detectable range minimum at 20cm and maximum up to 300cm.	- High operating power requirement - Expensive (RM 4540)
LEGO Mindstorms NXT IRSeeker V2 Infrared Sensor	- consists of specially designed curved lens and five internal detectors - wide coverage of scanning area up to 240° - uses advanced digital signal processing techniques	- Only compatible with LEGO Mindstorms NXT Microprocessor - Expensive (RM 199.80)
Sharp GP2Y0A02YK0F Infrared Proximity Sensor	- cost-effective (RM 59.80) - Medium scanning range between 15cm and 150cm - Power saving	- Limited scanning area and does not cover wide angle

Table 1 : Infrared Sensor Pros and Cons

CHAPTER 3

METHODOLOGY

3.1 Hardware Implementation

Figure 6 : Hardware Used for the Project (Arduino Mega, Sharp GP2Y0A02YK0F Infrared Sensor and Servo Motor)[2]

The prototype is designed by utilizing Sharp GP2Y0A02YK0F infrared proximity sensor and servo motor. This model is a reflectance sensor where the transmitter and receiver are already installed side by side. Arduino Mega is utilized to control rotating infrared sensor and to process the data obtained in order to identify the shapes of the detected objects. A control mechanism will be designed to control the rotational speed of each servo motor in order for the prototype to collect results based on the capability and the limit of the IR sensor.

3.2 Software Implementation

On the software side, Arduino IDE and Mathworks MatLab are used for this project. Arduino IDE is used to upload the control code to the Arduino Mega to obtain distance data from the infrared sensor and to rotate the servo motor. After obtaining the data, the program will then push the data to the serial port. Mathworks MatLab is used to receive data from the serial line, process it and visualize it into a graph.

3.3 Design of the Prototype

Design 1

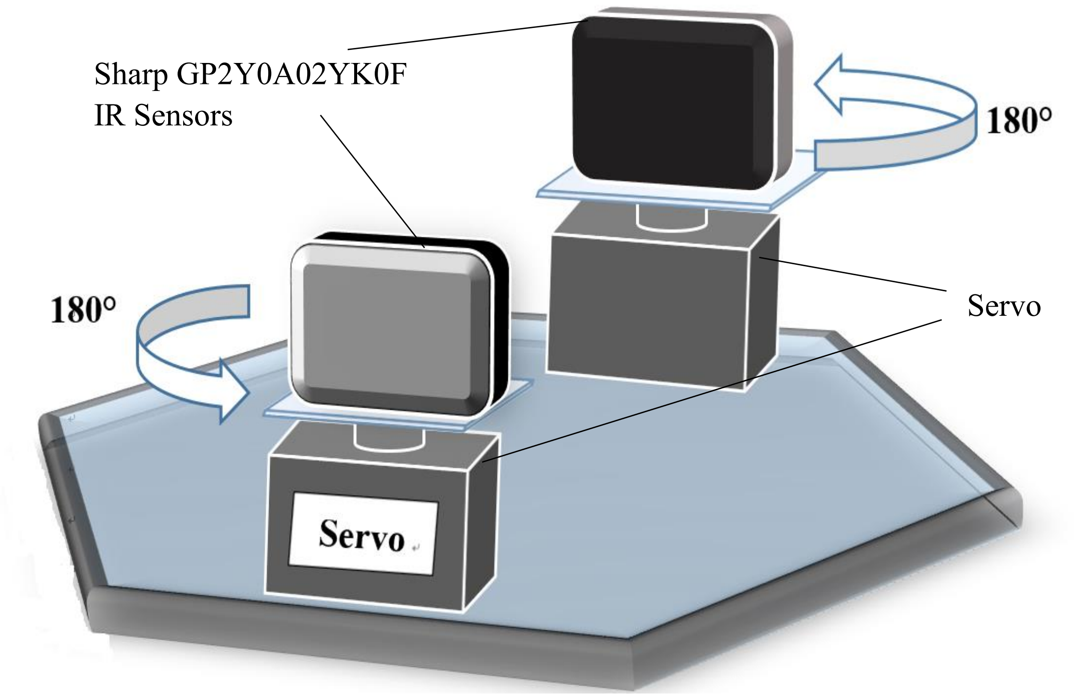


Figure 7 : Prototype Design 1

For the Design 1, two Sharp GP2Y0A02YK0F IR sensors are placed back-to-back to each other, with the rear of the one sensor facing the rear of the other sensor. Each IR sensor is then attached to a servo motor. Movement of the both servo motors will then be controlled by an Arduino microcontroller. Each servo motor rotates up to 180°, thus two identical motors can make a full sweep of nearly 360°. Henceforth, the prototype can detect objects within a 2D circular region.

Design 2

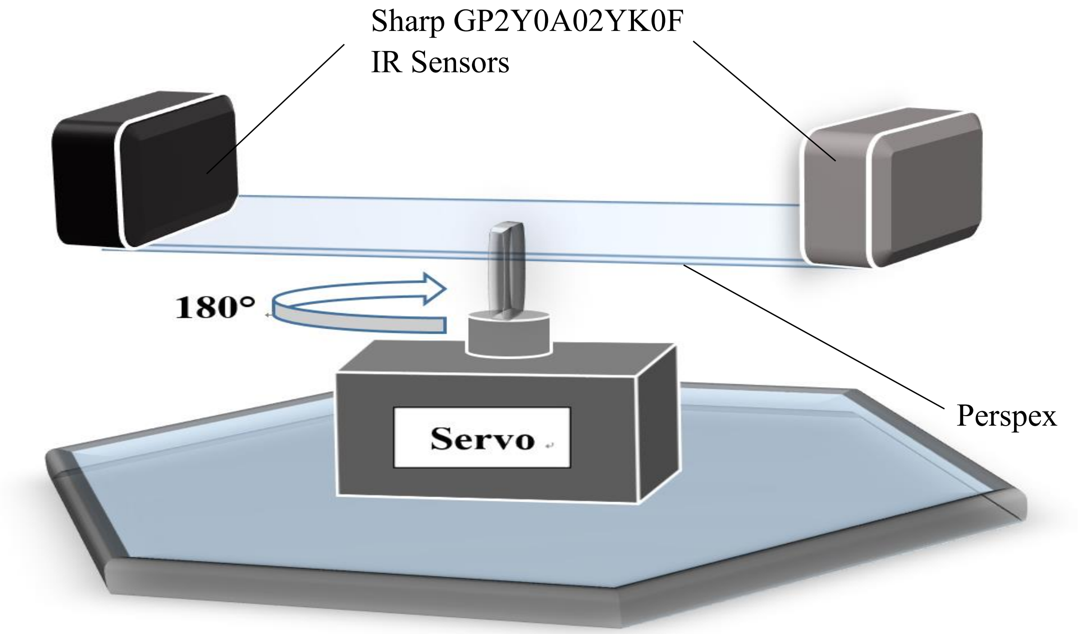


Figure 8 : Prototype Design 2

For the Design 2, two Sharp GP2Y0A02YK0F IR sensors are placed back-to-back to each other on a Perspex. The Perspex is then attached to a servo motor and the movement of the servo will then be controlled by an Arduino microcontroller to rotates up to 180°. With the two IR sensors, a full sweep of nearly 360° can then be covered. Henceforth, the prototype can detect objects within a 2D circular region.

3.4 Comparison of the Prototype Designs

Prototype / Feature	Design 1	Design 2
Complexity	Slightly higher	Medium
Power Consumption	High	Medium
Cost	Slightly higher	Medium
Rotating Speed	Medium	Slow
Stability	High	Medium

Table 2 : Design Pros and Cons

By comparing Design 1 with the Design 2 and looking at their designs' pros and cons, the result shown that although both the designs are able to have wide detection capability up to 360°, the designs require high power Consumption and are complex and also expensive. Although having wide detection capability is one of the requirements of the project, being cost-effective is also another main criteria to be fulfilled in the project. Therefore, an another design (Final Design) which can have wide detection capability but at the same time are less complex, requires lower power Consumption and most importantly cost-effective would have to be implemented.

Final Design

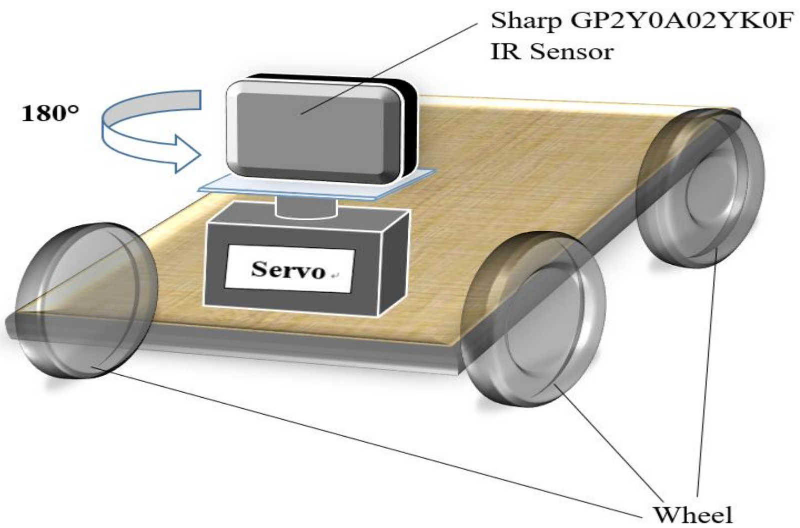


Figure 9 : Final Design of the Prototype

The Final Design of the prototype uses only one Sharp GP2Y0A02YK0F IR sensor and only one servo motor. The IR sensor is attached to the servo motor and the movement of the servo will then be controlled by an Arduino microcontroller to rotates up to 180°. Although the detection capability of the prototype can cover only up to 180°, by increasing the number of sweeps done by the servo at different directions, the prototype can cover a 2D circular region, up to 360°. Apart from that, the prototype is less complex, power-saving and cost-effective.

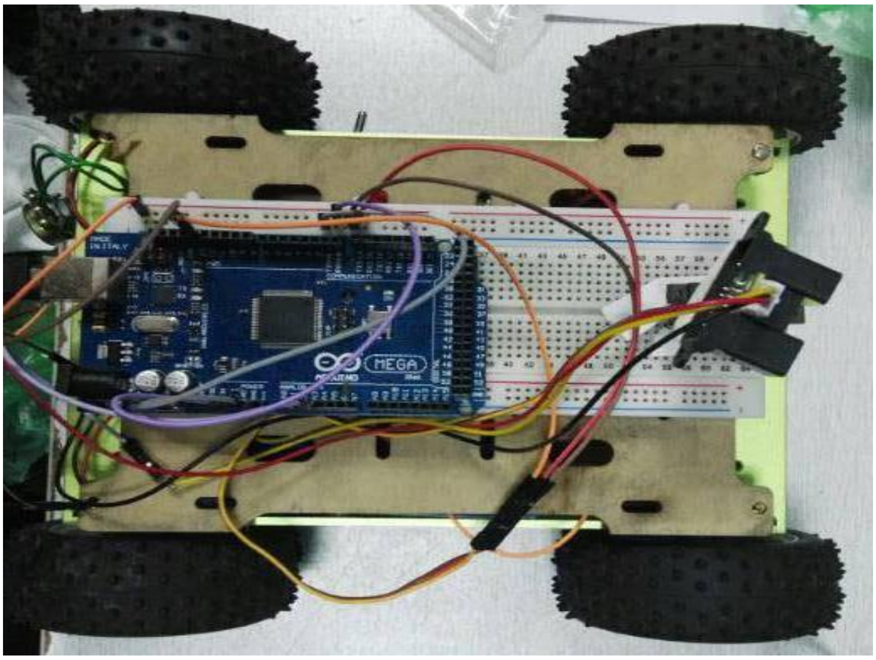


Figure 10 : Top View of the Prototype

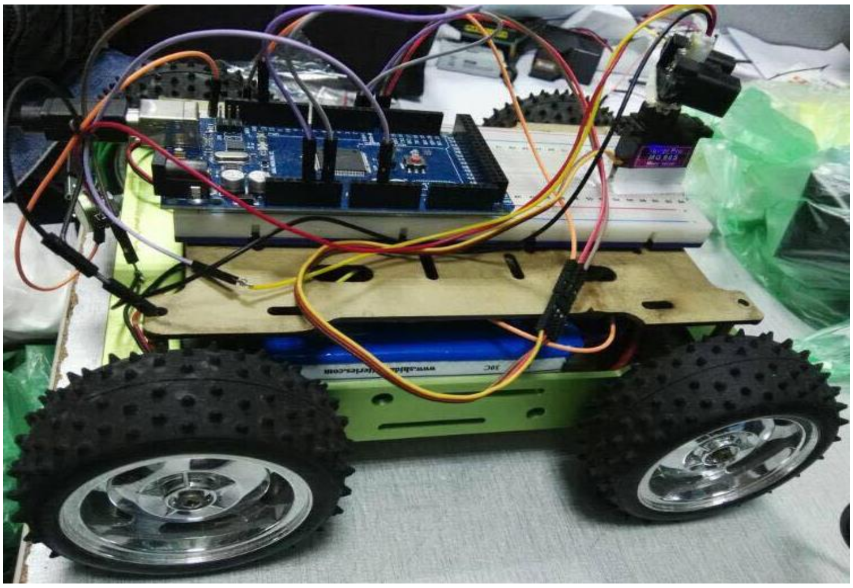


Figure 11 : Side View of the Prototype

3.4 The Arduino and The MatLab Codes

The Arduino board controls the rotation of the servo motor, when and how frequent the readings are captured. The servo is rotated by 15° for each interval and with 24 intervals the servo covers a full 360° rotation. At each angle, 10 distance data are captured by the infrared sensor and an average of the readings are computed. The average is then sent to the serial port and the process is repeated until all the readings are obtained.

The data received from the Arduino gives information on two parameters, (i) the degree of rotation of the servo and (ii) the distance of an obstacle in that direction. At this point the data obtained is still in the Polar coordinate system. In order to make sense to human eyes when visualized, the data has to be converted to the Cartesian (X-Y) coordinate system.

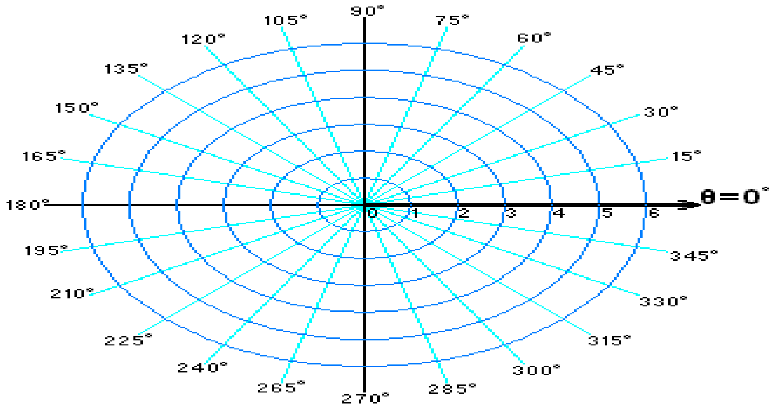


Figure 12 : Polar Coordinate System[3]

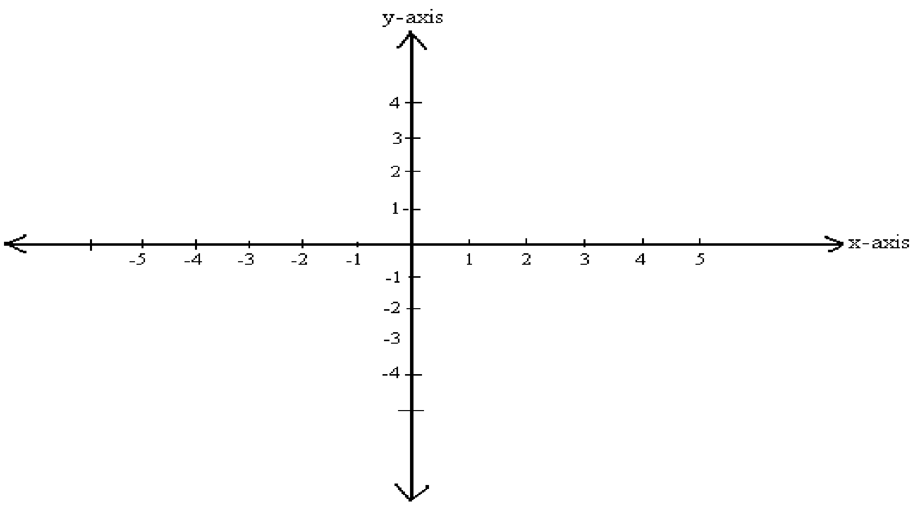


Figure 13 : Cartesian Coordinate System[4]

The MatLab code gets data serially from the COM port, stores the data into a matrix with the angle of rotation, and then converts it into Cartesian coordinates with the formula as follow :

$$X\text{-coordinate} = d \sin \theta$$

$$Y\text{- coordinate} = d \cos \theta$$

where d is distance of the object in that particular angle and θ is the degree of the angle rotated by the servo.

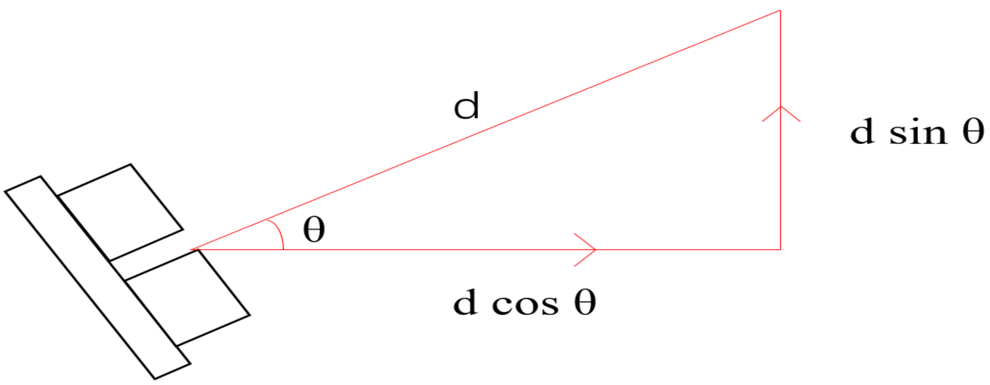
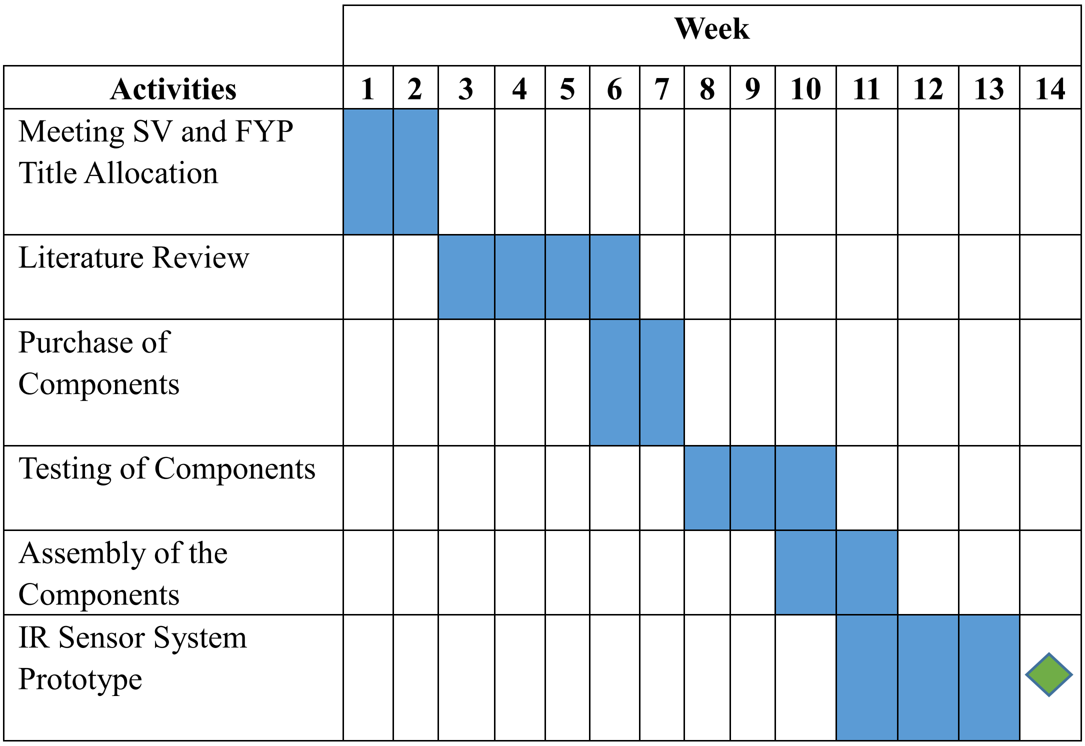


Figure 14 : Formula of X-coordinate and Y-coordinate[5]

After implementing the formula to find the X-coordinates and Y-coordinates, an output is generated by plotting points on a graph in which the graph represents a rough estimation of how the environment surrounding the prototype looks like and the distances of the obstacles are also shown.

3.5 Gantt Chart

<u>FYP I</u>



FYP II

	Week													
Activities	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Testing on the Rotational and Performance of the Prototype	■	■	◆											
Development of algorithm on sending the data from Arduino to Matlab				■	■									
Development of algorithm on performing the 2D area mapping						■	■							
Implementation of algorithm on performing the 2D area mapping								◆						
Testing and Improvement on the Accuracy and Sensitivity against known obstacles									■	■	■			
Implementation of full algorithm of the prototype												■	■	◆

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Distance Measurement of Object Using Sharp GP2Y0A02YK0F Infrared Sensor

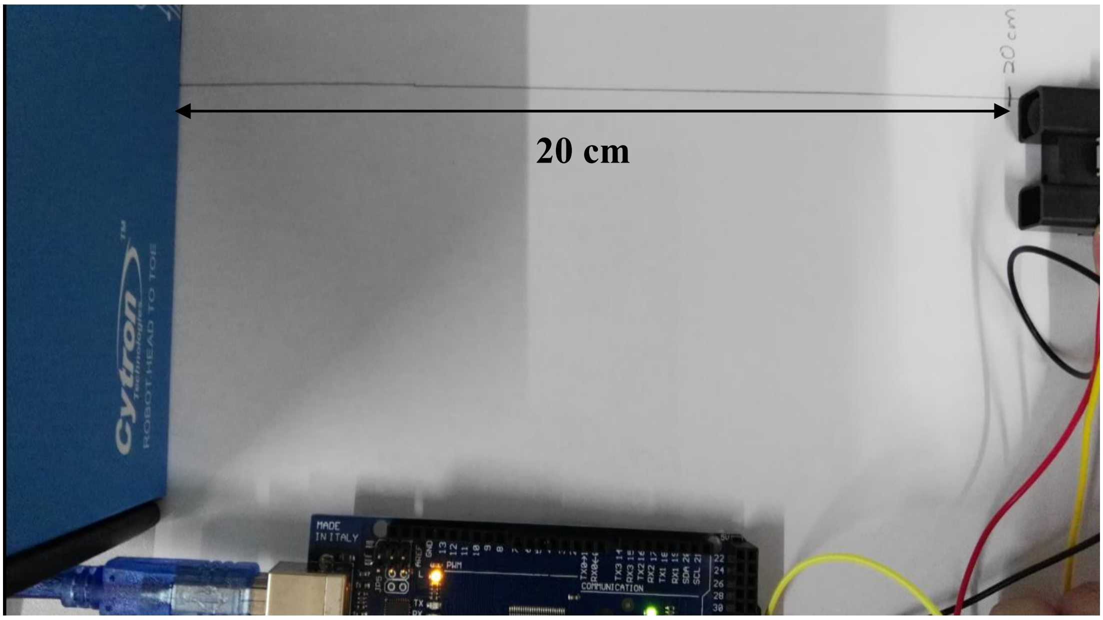


Figure 15 : Test Setup with Object Placed 20 cm from IR Sensor

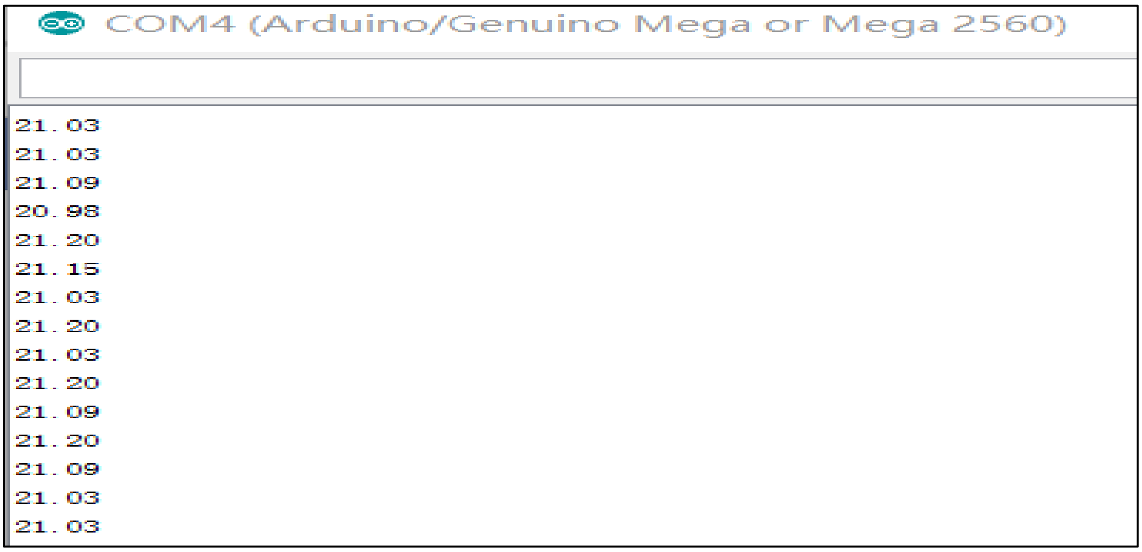


Figure 16 : Tested Results shown on Serial Monitor with Object at 20 cm

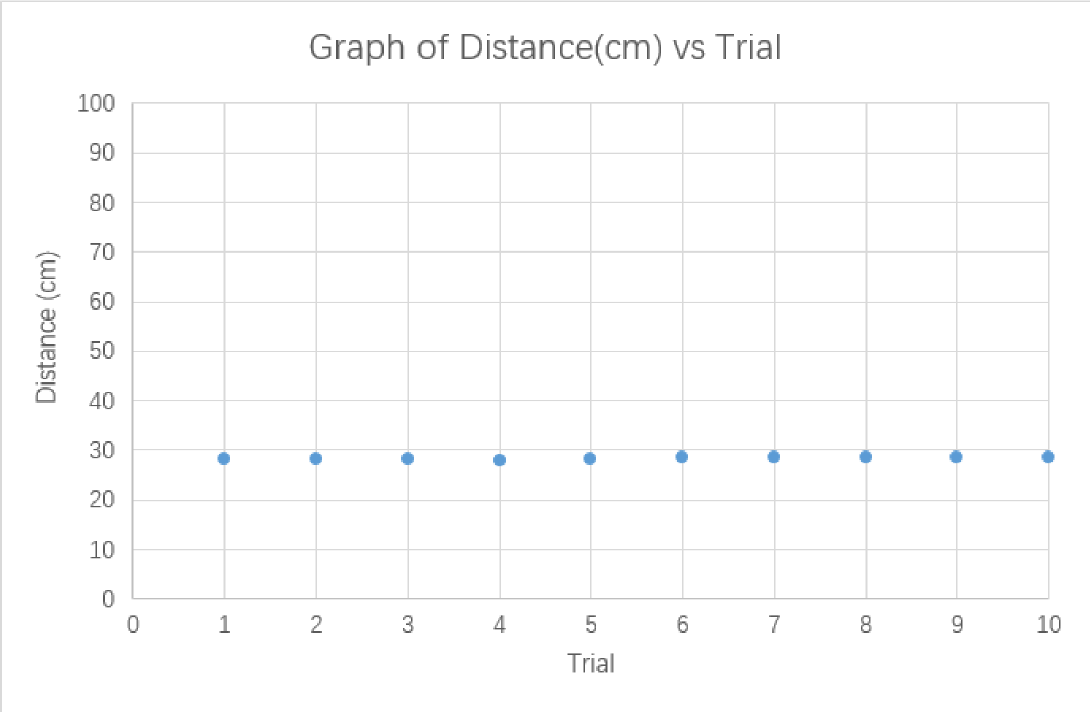


Figure 17 : Tested Results with Object Placed at 30cm

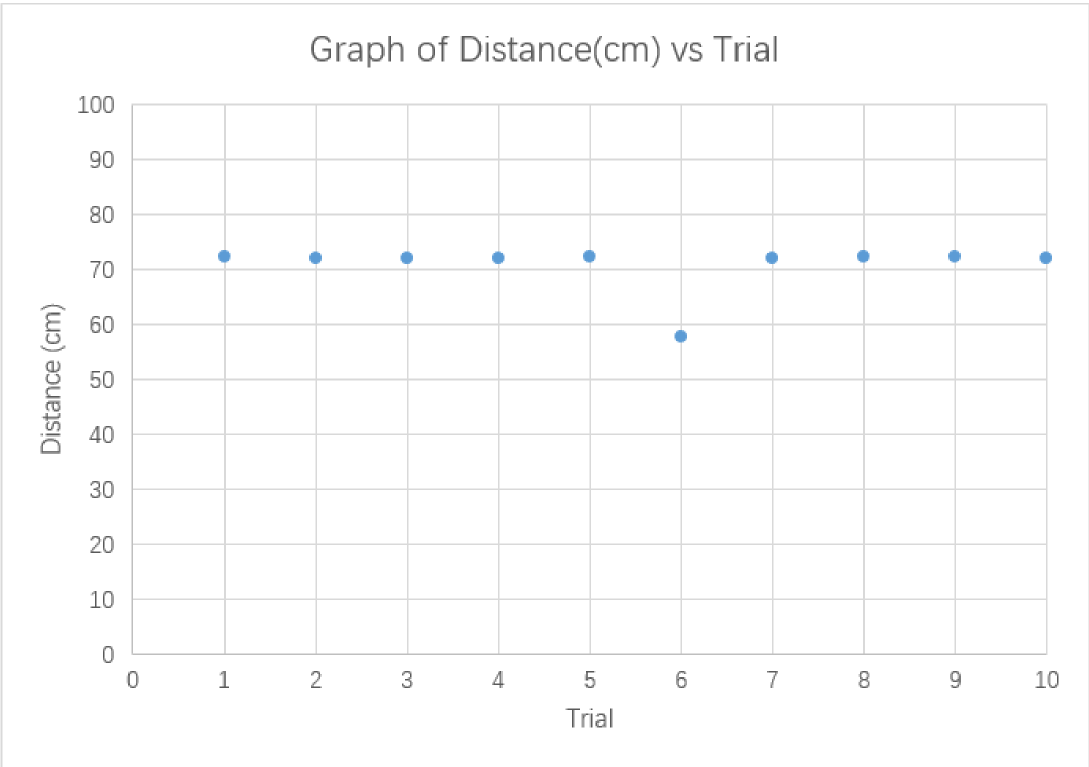


Figure 18 : Tested Results with Object Placed at 70cm

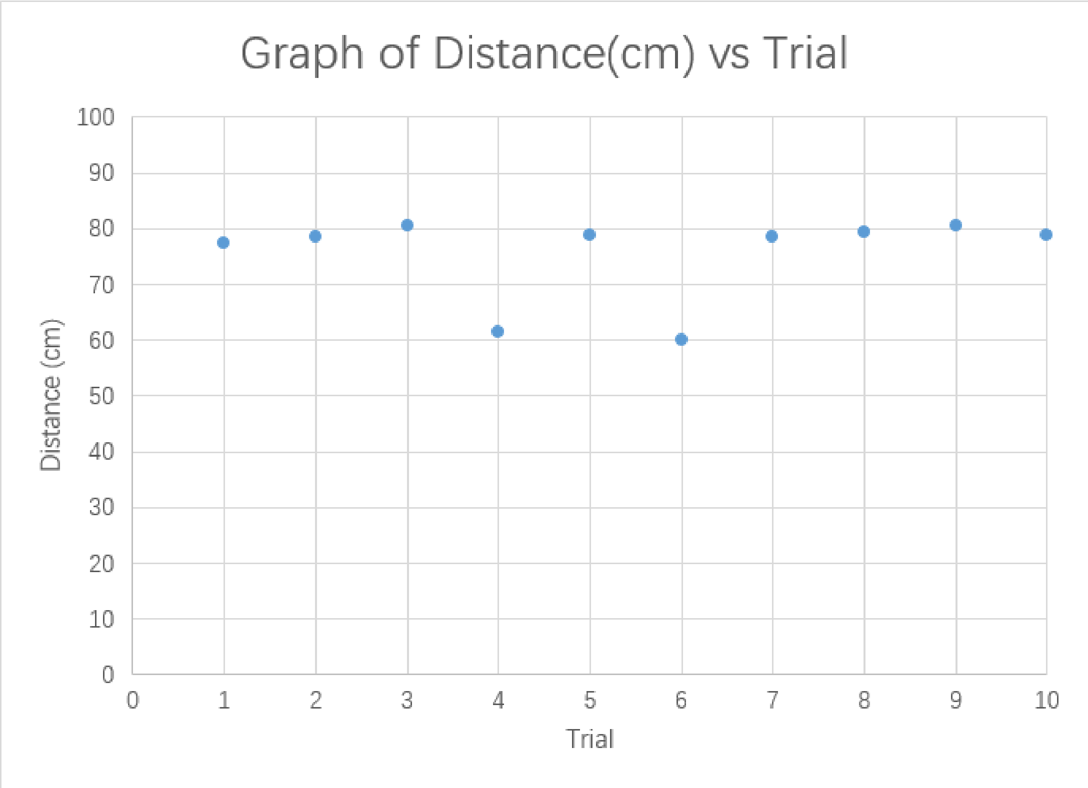


Figure 19 : Tested Results with Object Placed at 80cm

Testing on the distance measurement of object using the Sharp GP2Y0A02YK0F Infrared Sensor has been conducted. During the testing, the object at placed 20cm, 30cm, 70cm and 80cm away from the IR sensor respectively.

Results shown that the readings obtained are consistent and precise. However, the accuracy of the results varies between 1cm to 2cm. Furthermore, the longer the distance, the more the readings vary. This might be caused by the light intensity of the surrounding and also the shadow produced by the object. Therefore, an algorithm should be implemented on the prototype to avoid the shadow of the object detected and to obtain more accurate, at the same time more precise results.

4.2 Mapping of Surrounding at Static Point

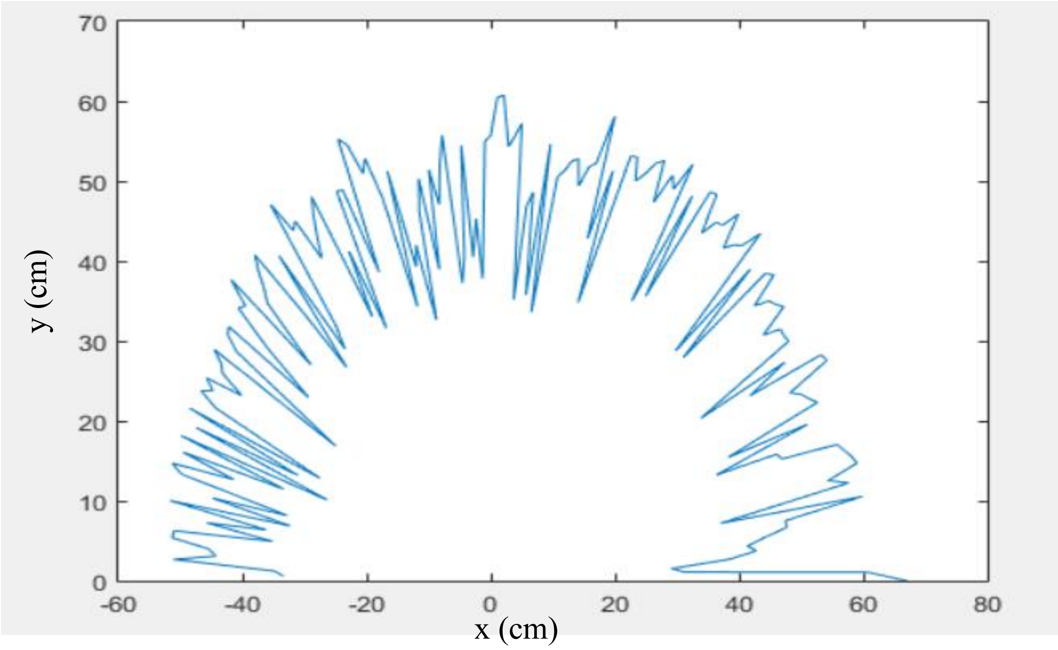


Figure 20 : Mapping of the Surrounding with No Obstacles

Above is the result obtained when static point mapping of the surrounding with no obstacles were carried out, by using only one infrared sensor (180° sweep). The graph roughly visualizes the surrounding though the system is not perfect. This is because of the errors due to the shaking of the sensor while the servo is moving and faulty readings from the sensor itself. Apart from this, the system works fine and further testing by putting obstacles before the IR sensor are carried out and the results are shown in the following figures.

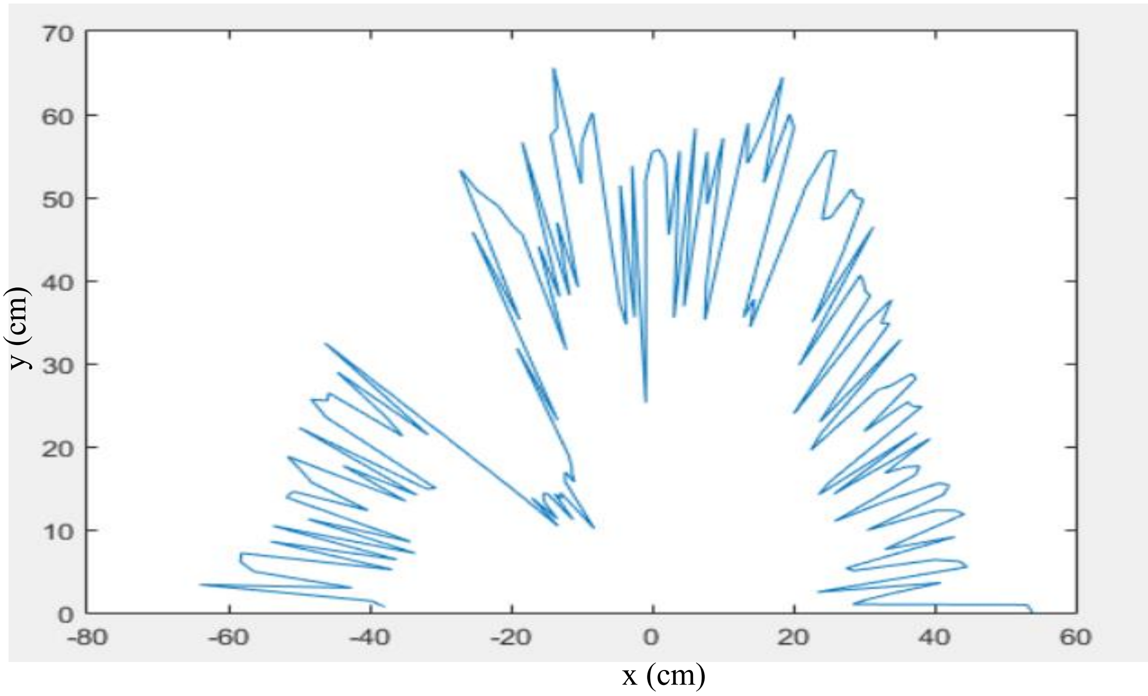


Figure 21 : Mapping of the Surrounding with Obstacle at 120° from the IR sensor

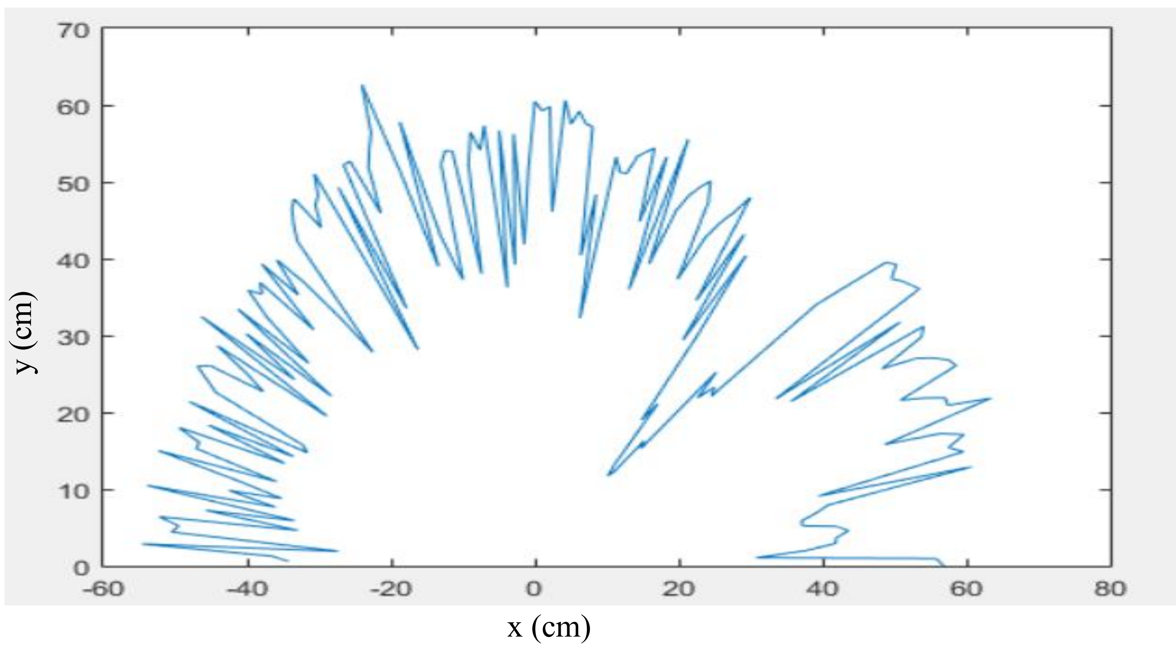


Figure 22 : Mapping of the Surrounding with Obstacle at 45° from the IR sensor

4.3 Mapping of Surrounding with Obstacle

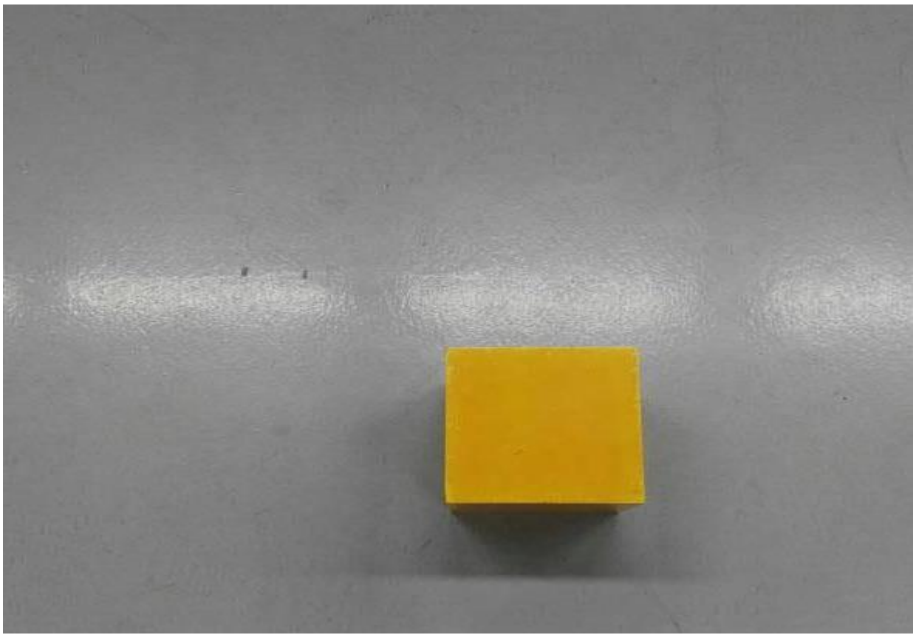


Figure 23 : Tested Setup with a Square used as Obtacle

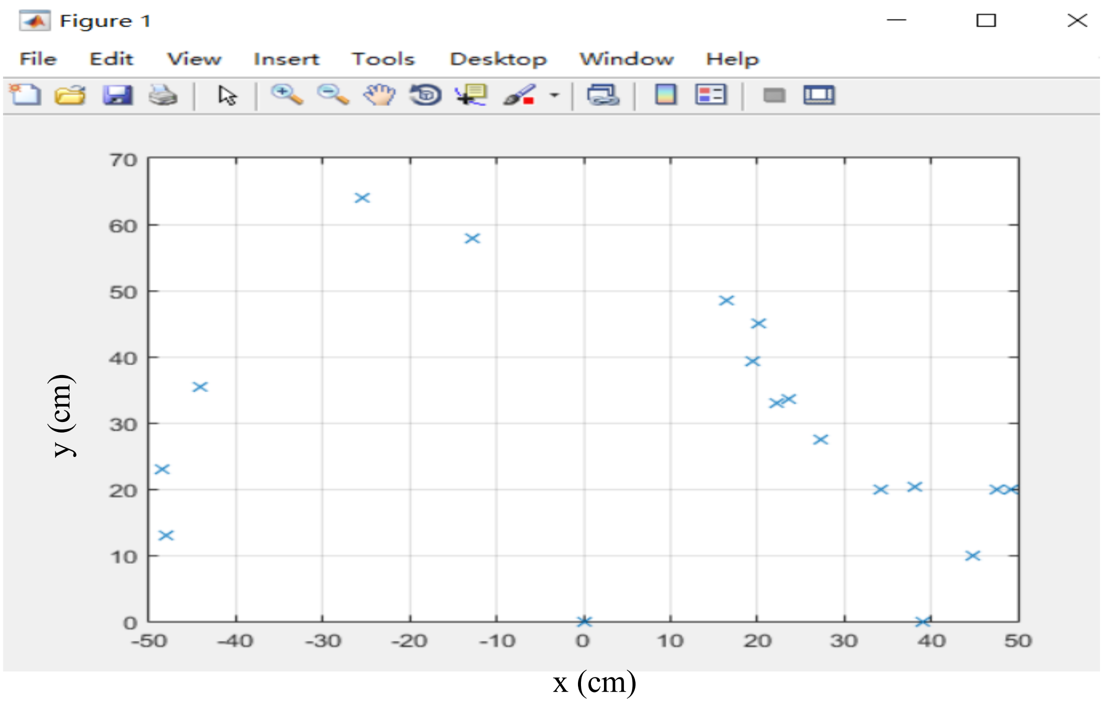


Figure 24 : Tested Result when a Square was used as the Obstacles(the prototype moved in straight line)

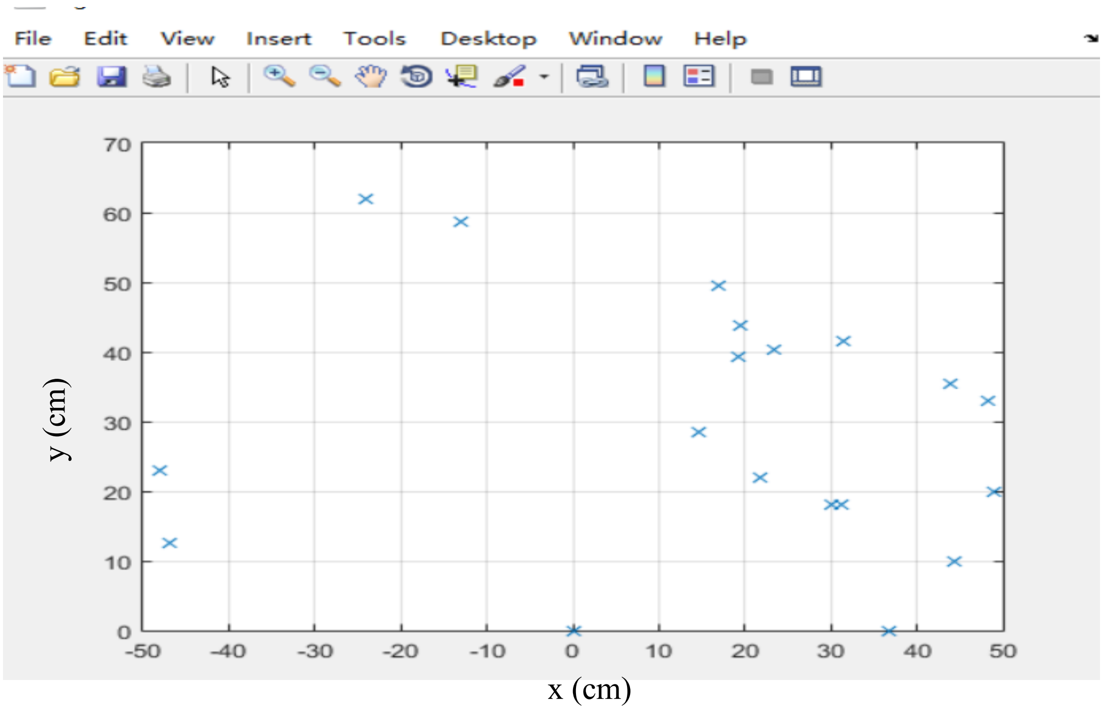


Figure 25 : Tested Result when a Square was used as the Obstacles(the prototype moved around the obstacle)

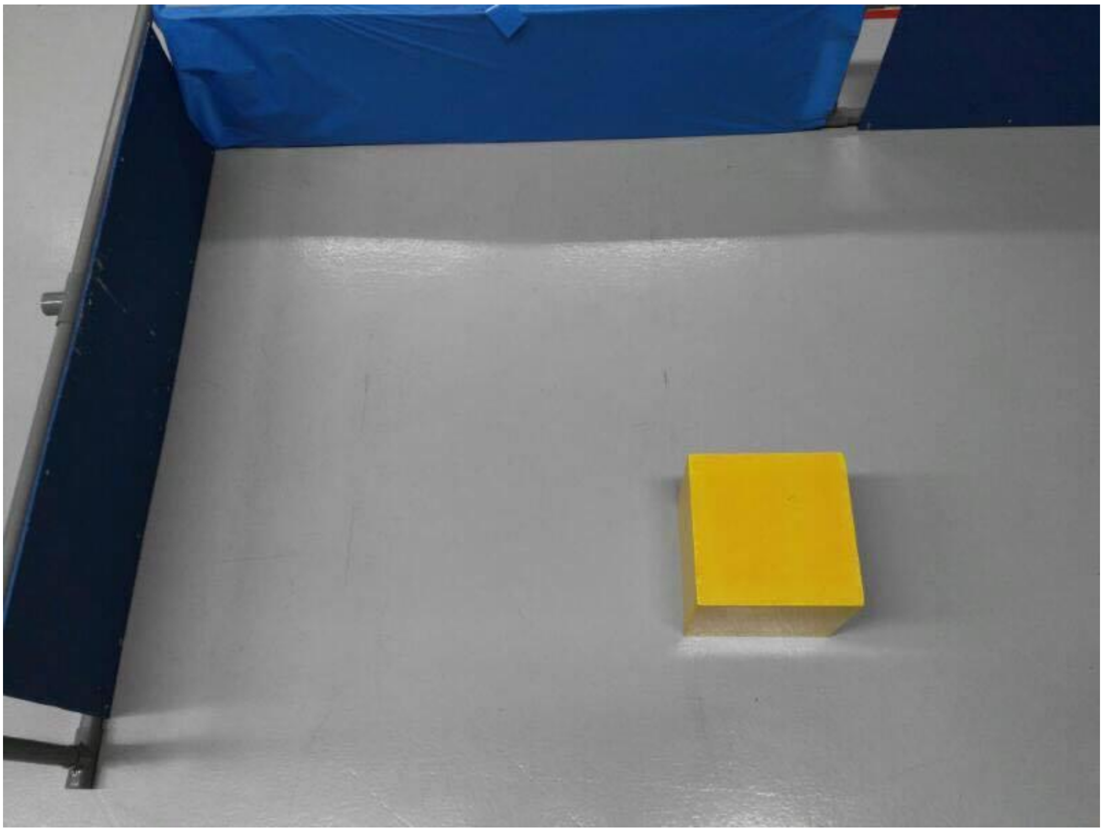


Figure 26: Tested Setup with a Square used as Obstacle with walls

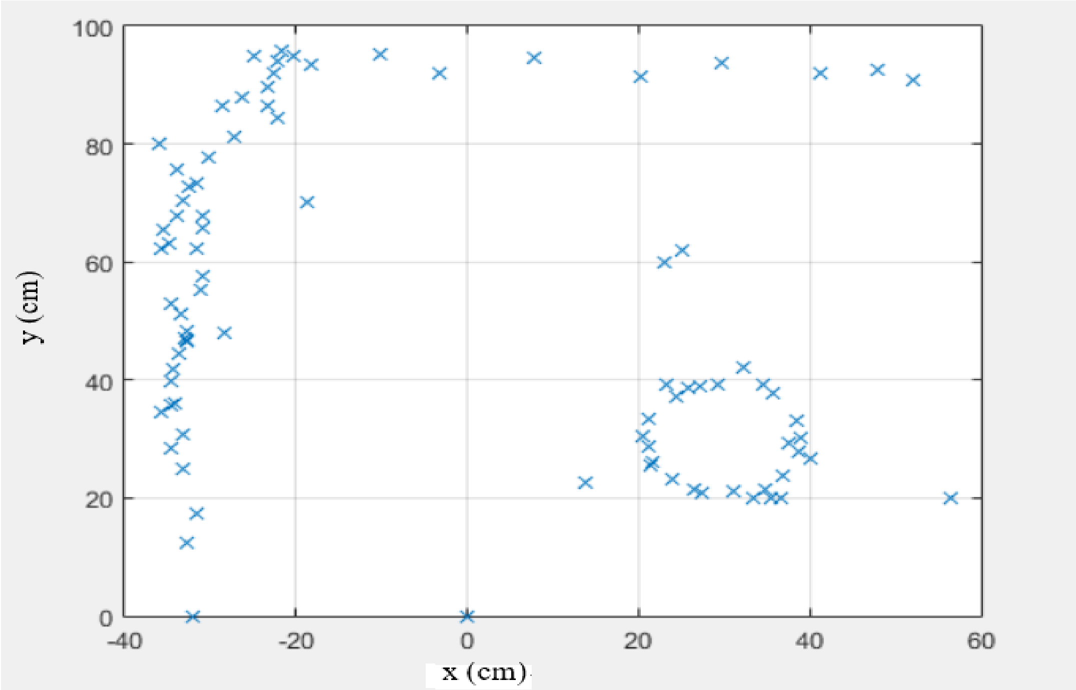


Figure 27: Tested Setup with a Square used as Obstacle with walls

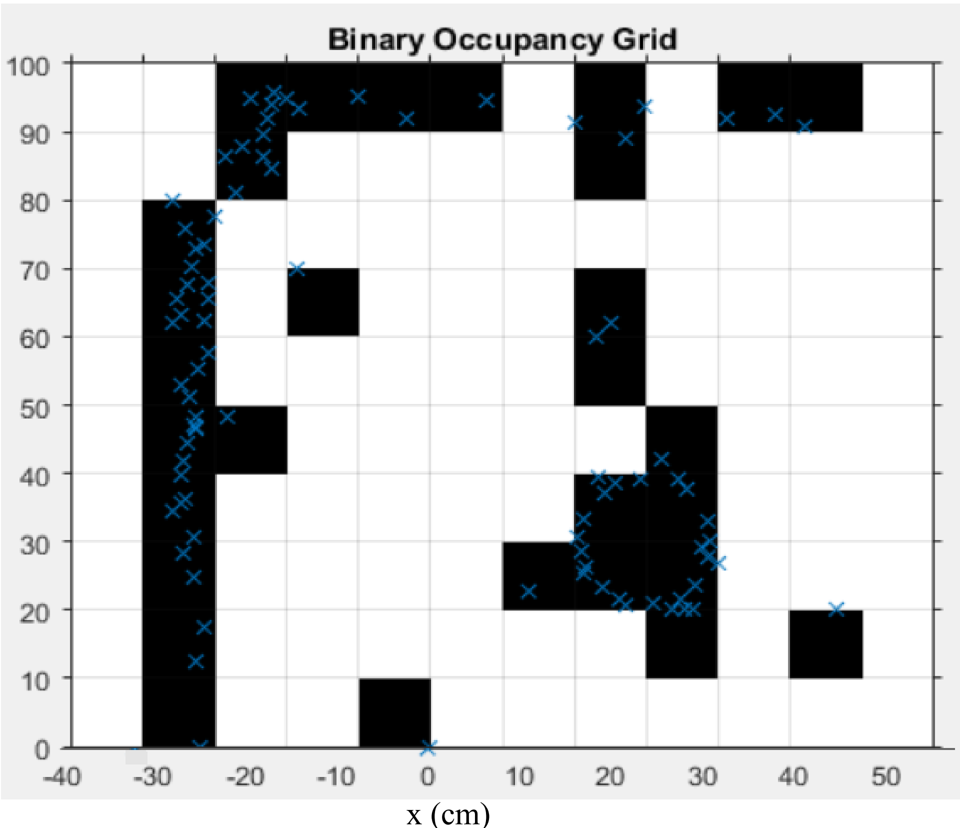


Figure 28 : Tested result by occupying the grid with obstacle

4.4 Limitation of the Infrared Sensor

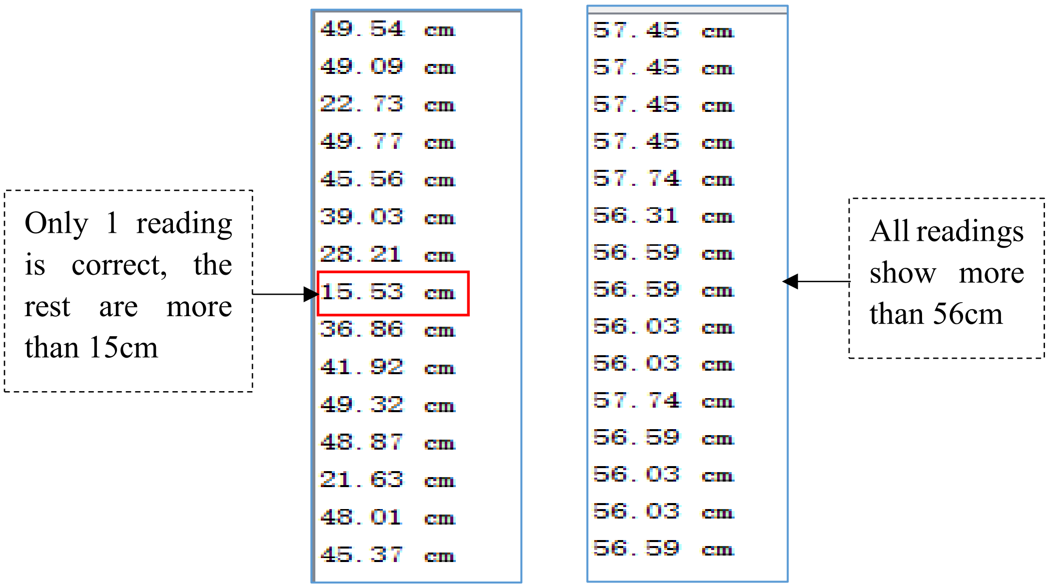


Figure 10 : Infrared Sensor Readings Measured at less than 15 cm (Left) and more than 150 cm (Right)

The figure above shows the readings obtained when the infrared sensor tried to measure the distance of an object at less than 15cm and more than 150cm from the sensor. The IR sensor gives false values because the detection range of the Sharp GP2Y0A02YK0F Infrared Sensor is between 15cm to 150cm. This may cause accuracy issues during the mapping and hence a solution to overcome the problem has to be implemented, that is by only taking the sensor’s readings that are lesser than 50cm.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

This project presents the utilizing of one infrared sensors and one servo motor to design a cost-effective rotating IR sensors prototype. Two features are being highlighted in this projects, that are low cost and wide angle scanning capability. Although accurate infrared sensors with wide area sensing capabilities can be easily found on markets, they are very expensive and not cost-effective. Therefore, this project is proposed.

Sharp GP2Y0A02YK0F infrared sensor and servo motor are used for this project. The IR sensors act as the main sensing and detecting tools whereas the servo motor is used to rotate the IR sensors, thus increases the angle covered in detection. Experiments will be carried out to test on the IR sensors' scanning capabilities and also the accuracy of the results especially on identification of the shapes of the detected objects.

Initial test on the distance measuring capability of the IR sensor was carried out. Based on the results obtained, the accuracy of the IR sensor will have to be further improved where the light intensity of the surrounding and the shadow caused by the object being detected ought to be put into consideration. Apart from that, the results obtained from the testing on the mapping of the surrounding area have proved that the system works fine on the mapping, however necessary improvements would have to be employed on the accuracy as well as the sensitivity against the objects detected.

For future work, it would be recommended to redesign the prototype's design for data collection. Multiples IR sensors could be used to improve the accuracy of the results obtained and to decrease the duration taken for collecting the data. Furthermore, it would be recommended to use more accurate but more expensive IR sensor which is the Hokuyo PBS-03JN Scanning Infrared LED Obstacle Detection Sensor to improve the accuracy of the results in both the distance measurement and the area mapping. This model of IR sensor came with usable scan that covers a 178.2° arc and a detectable range up to 300cm. Apart from that, a sturdier structure should be implemented on the rotating IR system to reduce the shaking of the sensor when the servo is moving. For instance, a damping mechanism could be applied between the IR sensor and the servo to minimize the vibration caused to the IR sensor that might contribute noises or errors to the data obtained. Last but not least, the Robotics System Toolbox, a Matlab supported add-ons application, should be used to obtain more accurate results on the 2D area mapping from the prototype.

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[11] “GP2Y0A02YK0F”, SHARP Corporation, Osaka, Japan. DATASHEET

[12] “MG90S, Metal Gear Servo”, Cytron Technologies, Johor, Malaysia. DATASHEET

APPENDIX

SHARP GP2Y0A02YK0F

GP2Y0A02YK0F

Distance Measuring Sensor Unit
Measuring distance: 20 to 150 cm
Analog output type

■Description

GP2Y0A02YK0F is a distance measuring sensor unit, composed of an integrated combination of PSD (position sensitive detector) , IRED (infrared emitting diode) and signal processing circuit.
The variety of the reflectivity of the object, the environmental temperature and the operating duration are not influenced easily to the distance detection because of adopting the triangulation method.
This device outputs the voltage corresponding to the detection distance. So this sensor can also be used as a proximity sensor.

■Features

1. Distance measuring range : 20 to 150 cm
2. Analog output type
3. Package size : 29.5×13×21.6 mm
4. Consumption current : Typ. 33 mA
5. Supply voltage : 4.5 to 5.5 V

■Agency approvals/Compliance

1. Compliant with RoHS directive (2002/95/EC)

■Applications

1. Touch-less switch
   (Sanitary equipment, Control of illumination, etc.)
2. Sensor for energy saving
   (ATM, Copier, Vending machine, Laptop computer, LCD monitor)
3. Amusement equipment
   (Robot, Arcade game machine)

Figure 11 : Description and Specifications of Sharp GP2Y0A02YK0F Infrared Proximity Sensor

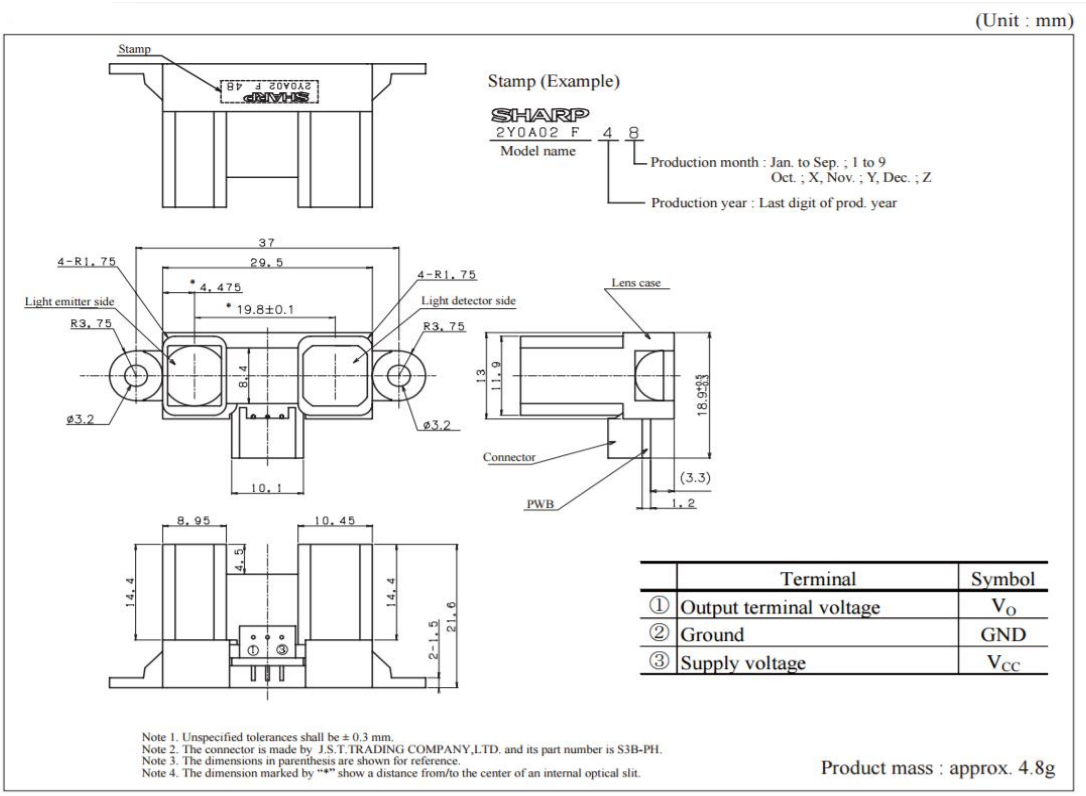

Figure 12 : Outline Dimensions of Sharp GP2Y0A02YK0F Infrared Proximity Sensor

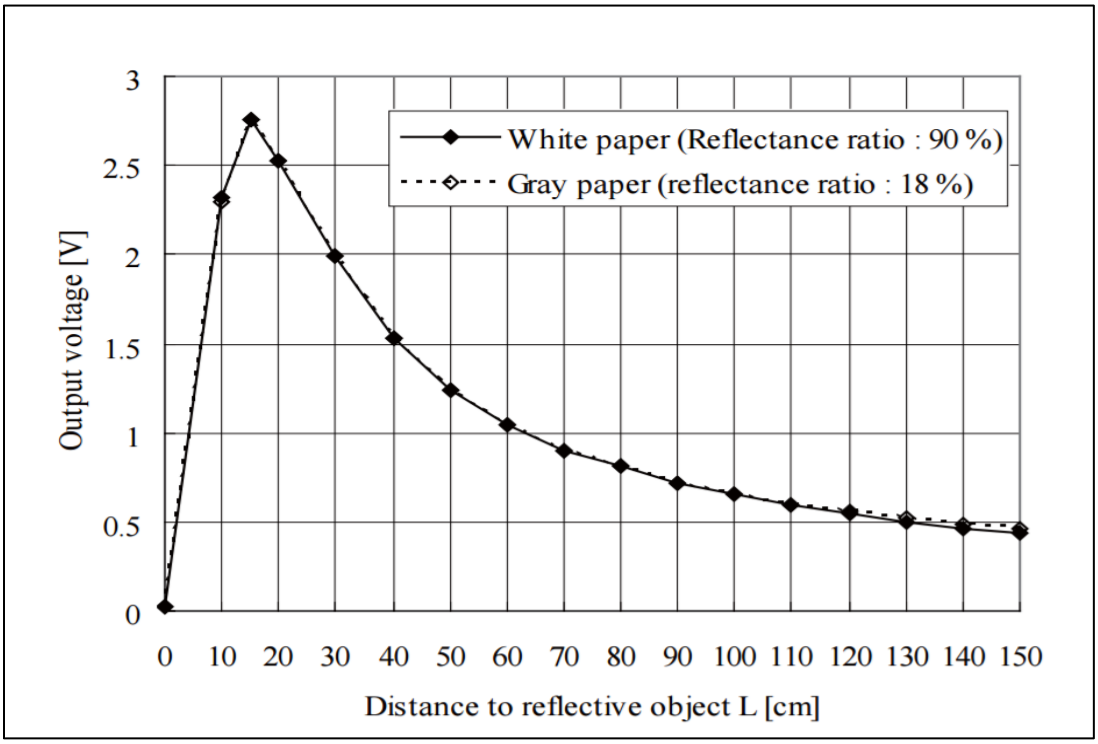

Figure 13 : Distance Measuring Characteristics (Output)

MG90S servo, Metal gear with one bearing

Tiny and lightweight with high output power, this tiny servo is perfect for RC Airplane, Helicopter, Quadcopter or Robot. This servo has *metal gears* for added strength and durability.

Servo can rotate approximately 180 degrees (90 in each direction), and works just like the standard kinds but *smaller*. You can use any servo code, hardware or library to control these servos. Good for beginners who want to make stuff move without building a motor controller with feedback & gear box, especially since it will fit in small places. It comes with a 3 horns (arms) and hardware.

Specifications

- Weight: 13.4 g
- Dimension: 22.5 x 12 x 35.5 mm approx.
- Stall torque: 1.8 kgf·cm (4.8V), 2.2 kgf·cm (6 V)
- Operating speed: 0.1 s/60 degree (4.8 V), 0.08 s/60 degree (6 V)
- Operating voltage: 4.8 V - 6.0 V
- Dead band width: 5 µs

Figure 14 : Description and Specifications of MG90S Servo

Arduino Code

```
#include <Servo.h>

#define sensorIR 15

float val ;
float dis ;
int cnt = 10 ;
Servo rotser ;

void setup()
{
   Serial.begin(9600) ;
   rotser.attach(9) ;
}

void loop()
{
   int i = 0 ;
   int t = 0 ;
   int a = 0 ;

   for (i = 0; i < 180; i++)
   {
      val = analogRead(sensorIR) ;
      dis = 10650.08 * pow(val,-0.935) – 11 ;
      rotser.write(i) ;
      delay(30) ;
      for (t = 0; t < cnt; t++)
      {
         val = analogRead(sensorIR) ;
         dis = 10650.08 * pow(val,-0.935) – 11 ;
         a = dis + a ;
      }
      a = a/ (cnt-1) ;
      t = 0 ;

      Serial.println(a) ;
      a = 0 ;
   }

}
```

MatLab Code

```
theta = 0:(pi/180):pi;
s = serial('COM3');
s.BaudRate=9600
fopen(s)
i = 0;

inc = 1;

while i<180
    A = fgets(s);
    num(i+1) = str2num(A);
    i = i+1;
end


j = 1

while j<181
     tab(j,1) = (j-1)*inc
     tab(j,2) = num(j)
     tab(j,3) = num(j)*cosd((j-1)*inc)
     tab(j,4) = num(j)*sind((j-1)*inc)
     j = j+1
end

plot(tab(:,3),tab(:,4))

fclose(s)
```