THE EFFECT OF FILTERING ON PROXIMITY SENSORS

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SIGNATURE PAGE

THESIS: THE EFFECT OF FILTERING ON PROXIMITY SENSORS

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ABSTRACT

In the world of automation, sensors play an important role as the eyes and hands of the machine. Two sensors that are observed in this thesis are the HC-SR04 sonar sensor and the Sharp GP2Y0A21YK infrared sensor. Each sensor has different properties and methods in which they calculate distance in the form of sound or light. In order for these proximity sensors to be considered effective, they should be able to detect a wide variety of targets with various properties including texture, size, positioning and color while being operated in different environments; however, this may not always be the case.

Multiple tests are performed on ultrasonic and infrared sensors to determine their accuracy using different filters to improve their outcome. Although not all filters used provide an optimal result for all the test cases, it is concluded that they do offer a slight improvement to the accuracy of the sensors. However, the position of the sensors with respect to the targets and its surroundings greatly affect the performance of the sensor as well as the different target textures, sizes and colors.

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CHAPTER 1

1.1 INTRODUCTION

As the world is advancing towards automation, the use of sensors has increased significantly in recent years. A variety of sensors, including proximity sensors, temperature sensors and pressure sensors, exist for different purposes such as autonomous vehicles, home automation, industrial robots, etc. As with all man-made devices, the accuracy and stability of the sensors are of huge concern. A common issue for engineers is the best positioning of the sensors to obtain the best performance and accuracy of measurements. This thesis aims to perform multiple tests on both ultrasonic sensors and infrared sensors, which are the two most common sensors used for distance measurement for object avoidance. These sensors are used to gather data for verifying and increasing their accuracy.

The following sections is explained in greater detail: the ultrasonic sensors, infrared sensors, signal processing and filtering, survey of the literature, and the goal of this thesis are explained in greater detail.

1.2 ULTRASONIC SENSORS

There exists a variety of ultrasonic sensors which range in both price and performance depending on the requirements of the work done. This section aims to cover the commonly used HC-SR04 model.

The HC-SR04 ultrasonic sensor shown in Figure 1 is utilized due to versatility as specified by Liu, Han, Lv and Li, “Ultrasonic sensors have been widely used in ITS and VANET area applications such as vehicle tracking classification, obstacle detection and mapmaking, vacant parking slot detection, smart traffic light signaling, ultrasonic ranging and localization, etc.” [1].

Figure 1 HC-SR04 Ultrasonic Sensor

An ultrasonic sensor calculates distance by using high frequency sound waves. They emit sound waves to detect targets, which leads certain factors such as color and transparency to have no effect on them. The measurement is taken by emitting a pulse at a specific frequency and listening for that sound wave to bounce back. This is known as the time of flight. Figure 2 in the following page illustrates the behavior of an ultrasonic sensor.

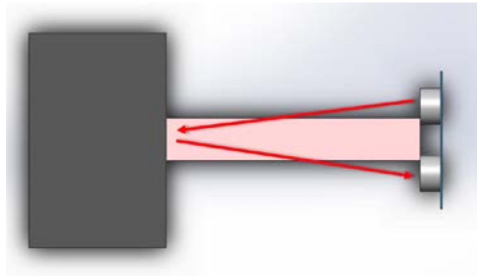

Figure 2 Ultrasonic Sensor Behavior

The elapsed time between the sound wave being transmitted and the sound wave being received is used to calculate the distance between the ultrasonic sensor and the target it detects, which can be calculated with Eq. 1.

$$distance = \frac{speed\ of\ sound * elapsed\ time}{2} \quad (1)$$

As observed in Eq. 1, the ultrasonic sensor relies heavily on the speed of sound in the air. As Gasparesc and Gontean mentioned in their article, the speed of sound in the air can be represented with Eq. 2

$$c = 331.45\sqrt{1 + \frac{T}{273}} \quad (2)$$

where T is the temperature in Celsius [2]. Eq. 2, proves that temperature heavily affects the performance of the ultrasonic sensors causing it to be a major factor. Eq. 2 could be simplified to Eq. 3 shown below.

$$c = 331.45 + 0.6T \quad (3)$$

Therefore, the speed of sound is 331.45 m/s at 0°C.

The sensor contains four pins, namely, Vcc, Trig, Echo, and Gnd. The trigger pin (Trig) is set to a high (5 volt output approximately or a logical 1) for 10 μs to trigger the sensor to send 8 cycles of sonic burst. The sonic burst is 8 cycles of a set frequency generated by the sensor, which sends a wave to the target. Then, if a target is detected, the echo is at high for a duration of time depending on the proximity of the device that has been detected. The cycle begins again after the echo is back to low as shown in Figure 3. The effective range for the sensor is 2 cm to 400 cm, and its measuring angle is 15 degrees on each side as mentioned in the datasheet [3].

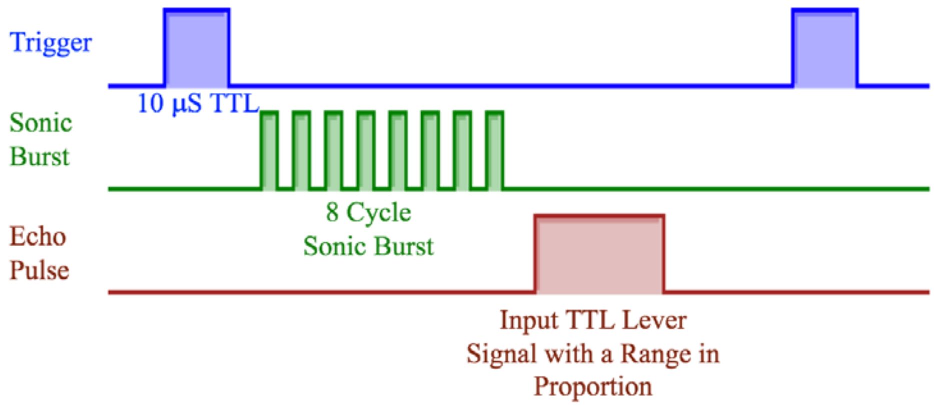

Figure 3 HC-SR04 Ultrasonic Sensor Timing Diagram

1.3 INFRARED SENSORS

Similar to ultrasonic sensors, there exists a variety of infrared sensors. They range in different pricing to different performance based on the requirements of the work done. This section aims to cover the commonly used Sharp GP2Y0A21YK Infrared (IR) Proximity Sensor (referred to as Sharp IR sensor from here on forth) discussed more in depth in this section.

The Sharp IR sensor is used for similar reasons as the HC-SR04 ultrasonic sensor, and its better-cost performance ratio as Adarsh, Kaleemuddin, Bose and Ramachandran mentioned in their article [4]. The IR sensor emits a light in the IR spectrum in order to detect aspects of its surroundings. The sensor consists of a light sensor and an LED. The LED produces light at the same wavelength that the sensor can detect, therefore, the emitter is nothing more than an IR LED, and the detector is simply an IR photodiode that is sensitive to IR light of the same wavelength emitted by the IR LED [5]. IR sensor use a method known as triangulation for transmitting and receiving the signals. Figure 4 illustrates this method. The emitter transmits a ray of IR light. If target is detected, that ray is reflected off of it and received at the transmitting IR LED. The angle, commonly known as the incident angle, varies depending on the position of the target. It increases as the target moves further from the sensor.

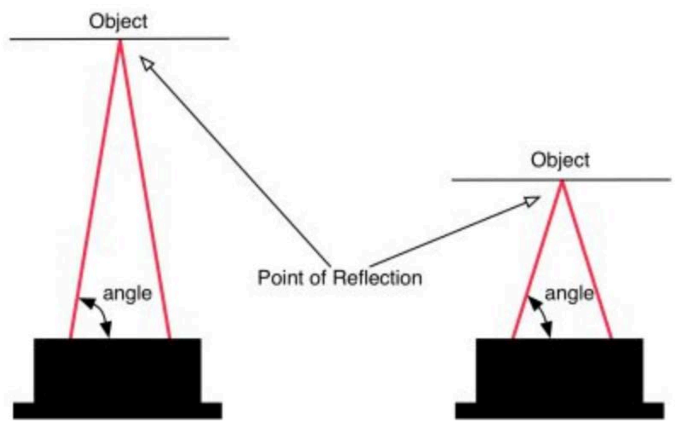

Figure 4 IR Sensor Triangulation Method [6]

The Sharp IR sensor shown in Figure 5 has three pins, GND, Vcc, and Vo. Vo provides a voltage range to detect the distance. The Sharp IR sensor's effective range is rated at 10 cm (equivalent to 3.1volt output) to 80 cm (equivalent to 0.4 volt output). Since the output is analog, an Analog to Digital Converter is required to obtain the result using any kind of processing unit unless the calculations are to be done purely by hand.

Figure 5 Sharp GP2Y0A21YK Infrared Proximity Sensor

Unlike the HC-SR04 ultrasonic sensor, the output and the distance reflected do not obey a linear relationship as shown in Figure 6 in the next page.

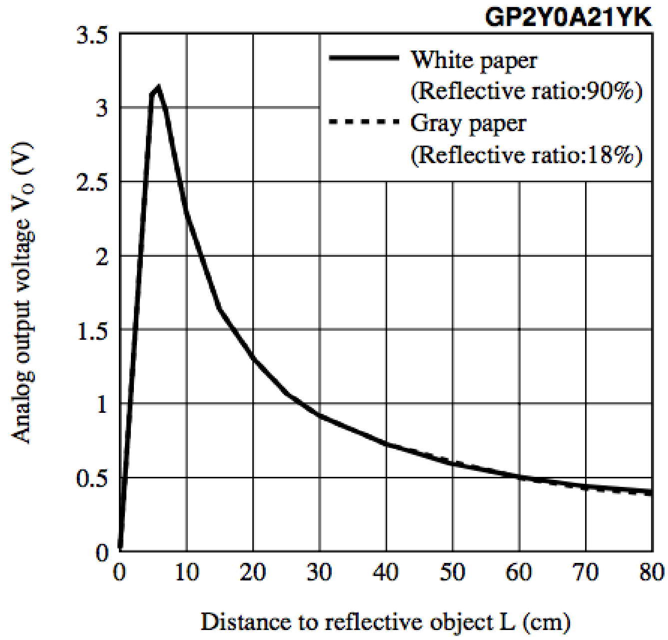

Figure 6 IR Sensor Analog Output vs. Distance [7]

However, similar to the HC-SR04 ultrasonic sensor, in order to obtain a measurement in terms of centimeters or inches, a function must be derived to convert the sensor output to voltage into a distance value. Eq. 4 is used for this specific Sharp IR sensor to obtain the distance from the voltage.

$$distance = \frac{30}{volt} \tag{4}$$

This equation produces a nonlinear result with distance versus voltage, as shown in Figure 6 above. A few methods are available to linearize the distance with respect to the voltage of the Sharp IR sensor, but this thesis is not going to cover this topic.

1.4 SIGNAL PROCESSING AND FILTERS

Sensors, like many devices, produce some signal. Certain external factors are prone to generate unwanted noise added to the signal which yields inaccurate results. To cancel or minimize the noise generated, the signal undergoes a process known as signal processing. Two types of signal processing exist, analog signal processing and digital signal processing. Analog signal processing involves the use of analog filters using circuit elements. Digital signal processing involves the use of software filter modules. Both perform similar work but the components used are slightly different [8]. For the scope of this thesis, the use of digital signal processing would be more convenient.

For both the HC-SR04 ultrasonic sensor and the Sharp IR sensors, there are two stages of filtering involved. The first stage (Filter 1 as depicted in Figure 7) involves removing any distance values larger than 400 cm or less than 0 cm since the datasheet specified the effective range as 0 cm to 400 cm for the HC-SR04 ultrasonic sensor; for the Sharp IR Sensor, it removes any distance values larger than 80 cm and less than 10 cm. The second stage (Filter 2 as depicted in Figure 7) involves the number of samplings taken into consideration as well as the process involved to yield more accurate results. The first three set of filters that were used takes the average of 10, 5 and 3 samples respectively. This type of filter is known as the average filter. The second three set of filters that were used takes the median of 10, 5 and 3 samples respectively. This type of filter is known as the median filter. The last two set of filters that were used take 10 and 5 respectively, removes the minimum number of the samples, the maximum number of the samples, then the average of the new set of samples is taken.

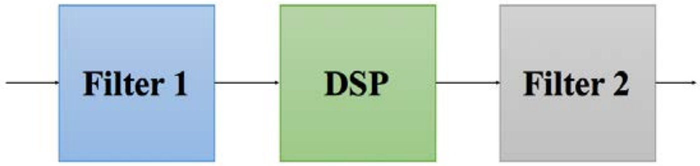

Figure 7 Filter Block Diagram

Table 1 provides a list of the filters used as Filter 2 in Figure 7 for the experiments.

Filter 2	**Explanation**
Filter A	The average of 10 samples is taken. $$Final\ Distance = \frac{\sum_{i=1}^{10} Sample_i}{10}$$
Filter B	The average of 5 samples is taken. $$Final\ Distance = \frac{\sum_{i=1}^{5} Sample_i}{5}$$
Filter C	The average of 3 samples is taken. $$Final\ Distance = \frac{\sum_{i=1}^{3} Sample_i}{3}$$
Filter D	The median of 10 samples is taken. $$Final\ Distance = Median(Sample_i)_{i=1}^{10}$$
Filter E	The median of 5 samples is taken. $$Final\ Distance = Median(Sample_i)_{i=1}^{5}$$
Filter F	The median of 3 samples is taken. $$Final\ Distance = Median(Sample_i)_{i=1}^{3}$$
Filter G	The median of 10 samples is taken.

Filter 2	Explanation
	$Final\ Distance = \frac{\sum_{i=1}^{10} Sample_i - Min(Sample_i)_{i=1}^{10} - Max(Sample_i)_{i=1}^{10}}{8}$
Filter H	The median of 5 samples is taken. $Final\ Distance = \frac{\sum_{i=1}^{5} Sample_i - Min(Sample_i)_{i=1}^{5} - Max(Sample_i)_{i=1}^{5}}{3}$

Table 1 List of Filters

1.5 SURVEY OF THE LITERATURE

The performance of ultrasonic sensors has been studied in multiple research articles [2] [4] [9]. However, not many reliable studies have been found on the performance of IR sensors. This section summarizes the work previously done by other authors.

Gasparesc and Gontean performed similar research with ultrasonic sensors [2]. The ultrasonic sensors used in their research were the NXT and Parallax Ping sensors. They only performed tests on three different target sizes and performed linear regression on the results to improve the accuracy of the sensors.

Adarsh et al. extended the performance of a variety of tests on infrared and ultrasonic sensors using different targets of different materials [4]. They compare the performance of the two sensors by plotting the measured versus actual distance. They plotted the error, known as the deviation, which is the difference between the actual and measured distances. Adarsh et al. only focused on the target's texture and not other criteria that may affect the sensor's performance, nor did they provide a solution to the inaccuracy of the sensors.

Panda, Agrawal, Nshimiyimana, and Hossain focused their research on finding a relationship between the results of the sensor and the temperature of which the sensor is operating in to provide a solution for it [9]. Their concern is only within the short distance range and not the long distance. They did not perform tests on different targets and textures which may have an effect on the sensor's performance.

As previously mentioned in this section, majority of the research mostly focused on the performance of ultrasonic sensors. The tests performed were very limited, and not all factors that may affect the sensor's performance were considered. Only one of the research found suggested a solution to improve the accuracy of the sensor.

1.6 GOAL OF THESIS

The goal of this thesis is to test the accuracy and find the optimum solution to improve of the two types of sensors, namely, ultrasonic and infrared sensors, in different conditions and with different targets using a PIC18F4321 microcontroller as the processing unit. Although it is similar to research done in the survey of literature, the tests performed in this thesis are more intensive.

As explained in Section 1.2, the HC-SR04 ultrasonic sensor relies heavily on the speed of sound, and as mentioned in Section 1.4, most research performed dealt with the target's shape, size and texture as well as the temperature of the environment. In order to properly test the accuracy of this sensor, the factors that affect it need to be considered. Some factors that may have an effect on the HC-SR04 ultrasonic sensor are temperature and humidity as well as the target's texture, size and positioning with respect to the sensor.

For the Sharp IR sensor, it relies heavily on light in the IR spectrum. Therefore, the major factor affecting the IR sensor should be the color and opacity of the target as well as the lighting of the environment. However, in order to be able to better compare the two types of sensors, most tests performed on the HC-SR04 ultrasonic sensor is performed on the Sharp IR sensor with minor changes between some tests.

The two sensors mentioned above are thoroughly tested with different targets, different positioning, as well as different filtering methods. The tests performed and filtering methods used are discussed thoroughly in Chapters 2 and 3 for the HC-SR04 ultrasonic sensor and Sharp IR sensor, respectively.

CHAPTER 2

2.1 ULTRASONIC SENSOR SIMULATION SETUP, TEST RESULTS, AND ANALYSIS

The measurements for the HC-SR04 ultrasonic sensor were taken at 1 cm for the range [0 cm, 150 cm]. Although the sensor is capable of detecting targets up to 400 cm, the tests performed are limited to 150 cm. This is due to the size limitation of the environment which the tests were performed in. The target was placed on the ground and the sensor was leveled with the center of the target's height. Figures 8 to 10 illustrate a sample of the test setup with different views of the HC-SR04 ultrasonic sensor.

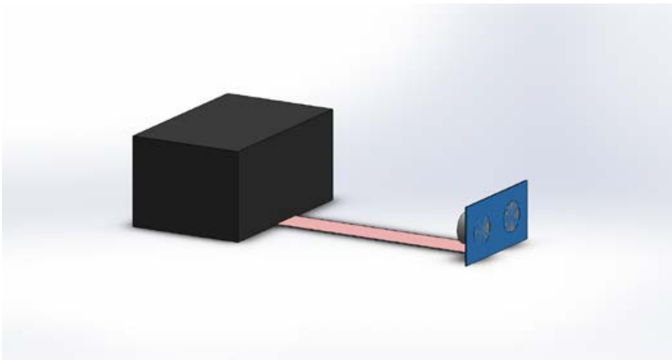

Figure 8 Ultrasonic Sensor Sample Test Setup - Angle View

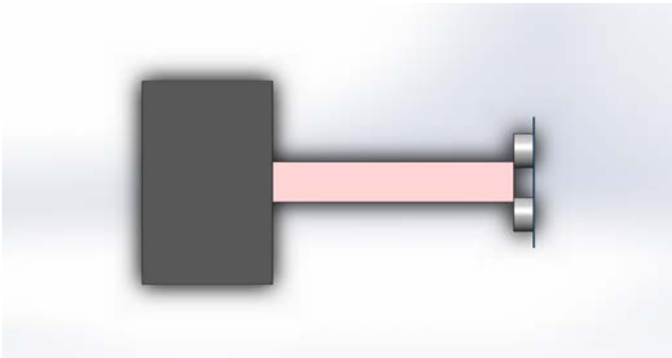

Figure 9 Ultrasonic Sensor Sample Test Setup - Top View

Figure 10 Ultrasonic Sensor Sample Test Setup - Side View

Test set 1 exams the performance of the sensor on different target textures. The size and shape of the targets were consistent. The color of the targets is negligible in this test. The target's environment was also consistent and the positioning of the target is set to be at 90° in front of the sensor. The target remained stationary during the measurements.

Test set 2 exams the performance of the sensor on different target sizes. The shape, color, and texture of the target were consistent as well as the target's environment, positioning, and motion as explained for test set 1. The texture best detected in test set 1 was used as the target's texture for this test.

Test set 3 exams the performance of the sensor at different angling of the target with respect to the sensor. Similar to test set 2, the texture and size best detected by test sets 1 and 2 were used as the target's texture and size for this test.

Each test set is thoroughly elaborated in the following sections of this chapter.

2.2 TEST SET 1 – TEXTURE

The variable for test set 1 is the texture of the target. The textures tested were stainless steel, cardboard, construction paper, and glass. The positioning of the target was consistent at 90° in front of the sensor, and the target was stationary throughout the entire test. The dimensions of the targets were also consistent. Each test case was performed with each of the filters in Table 1 in Section 1.4.

Using the filter which takes the average of 10 samples, the performance of the sensor on each texture is compared in Figure 11. It is evident that the glass tray and the construction paper were not detected as well as the stainless steel and cardboard were by the HC-SR04 ultrasonic sensor. Between the stainless steel and cardboard, the stainless steel yielded the best results. However, it is expected that glass would be detected better in comparison to a cardboard, but in reality, glass generated two major false readings. Therefore, the two best textures detected by the HC-SR04 ultrasonic sensor are stainless steel and cardboard.

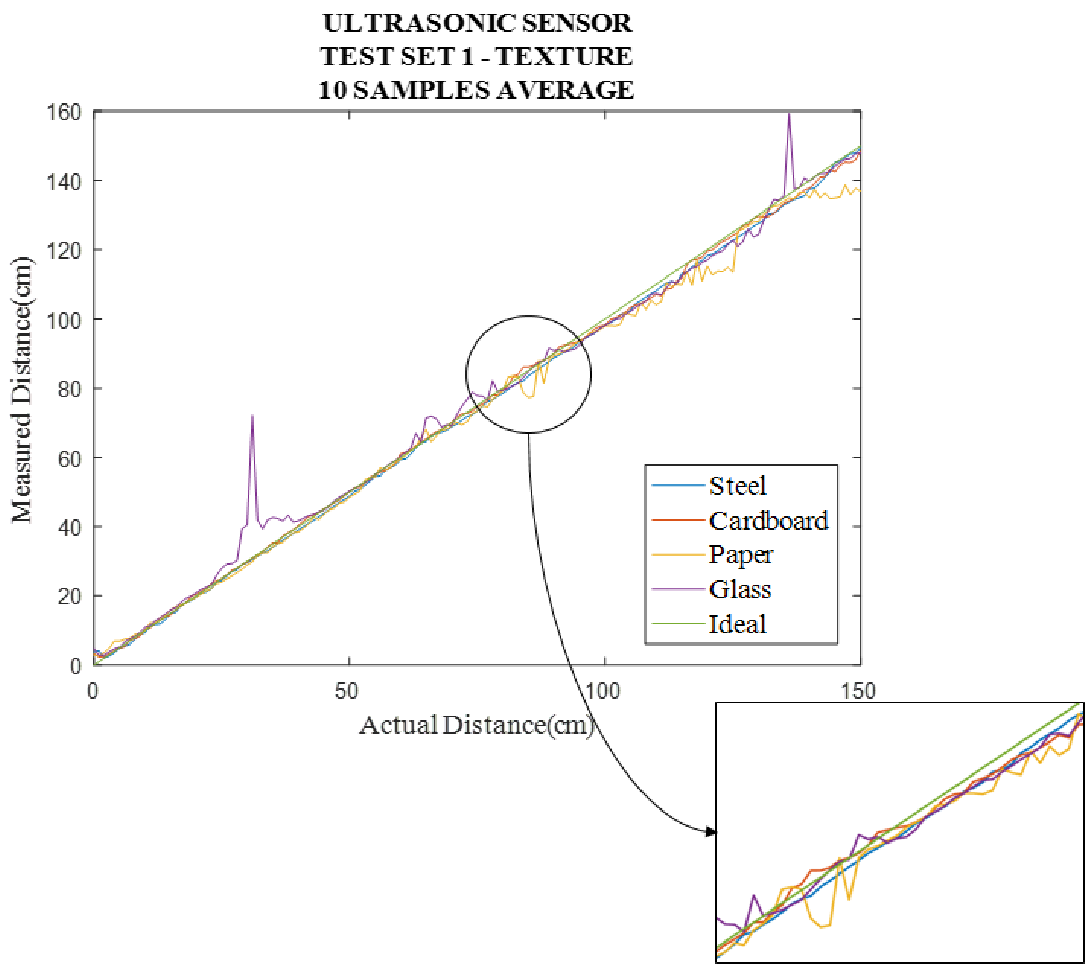

Figure 11 Ultrasonic Sensor - Test Set 1 Plot

2.3 TEST SET 2 – SIZE

The variable for test set 2 is the size of the target. Two sizes were tested: small and large. The larger size had been tested in test set 1. The targets' texture, shape, color, and positioning were consistent throughout the test, and the targets remained stationary throughout the duration of the tests. Each test case was performed with each of the filters mentioned in Table 1 in Section 1.4. Stainless steel was the texture of the target used.

Using the filter which takes the average of 10 samples, the performance of the sensor on the different sizes is compared in Figure 12. It is observed that the smaller sized stainless steel tray was not detected as well as the larger sized stainless steel tray. One reason may be that the smaller the size, the smaller the surface area, the larger chance of the sensor's wave to be reflected off of other surrounding objects.

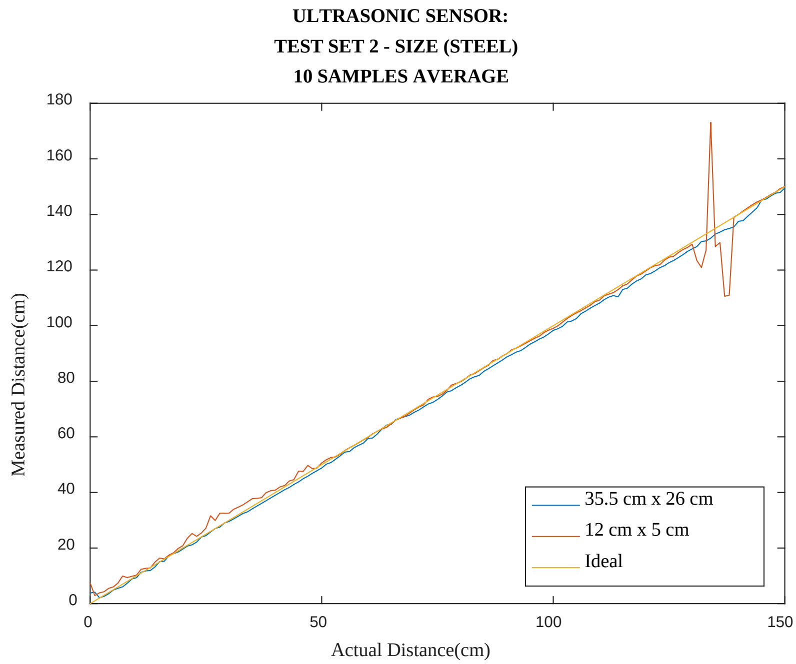

Figure 12 Ultrasonic Sensor - Test Set 2 Plot

2.4 TEST SET 3 – POSITIONING

The variable for test set 3 is the positioning of the target with respect to the sensor. In test sets 1 and 2, the targets were placed 90° in front of the sensor. For this test, the target is placed -15°, -10°, -5°, +15°, +10°, and +5°, where a plus sign denotes to the right of the sensor and minus denotes to the left as shown in Figure 13.

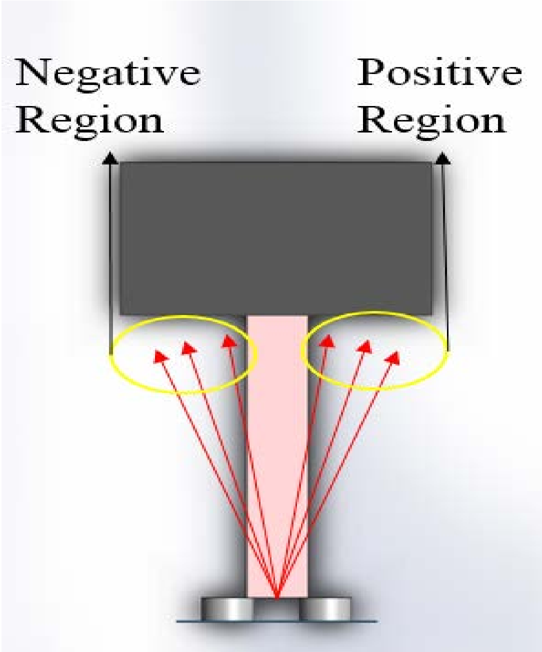

Figure 13 Ultrasonic Sensor - Positioning References

Due to the limitation of the test setup, the range of the distance measured for the angling is [0 cm, 93 cm]. The test was performed with all of the filters, and the target, a 35.5 cm by 26 cm stainless steel tray, that was best detected by the sensor in test sets 1 and 2. The test case that these are compared to is the test case found in test set 1 for the stainless steel tray. The target remained stationary throughout the duration of the test.

Using the filter which takes the average of 10 samples, the performance of the sensor on the positioning of the target with respect to the sensor is compared. As shown in Figure 14, the smaller the angling of the target with respect to the sensor, the more accurate the results were in comparison to the wider angling of the target position with respect to the sensor. Also, the side at which the target is positioned provides different results. This is due to the transmitter and receiver of the sensor. Placing the target closer to the receiver would yield better results as opposed to placing it further away from the receiver. Overall, the position that yielded the best result was directly in front of the sensor.

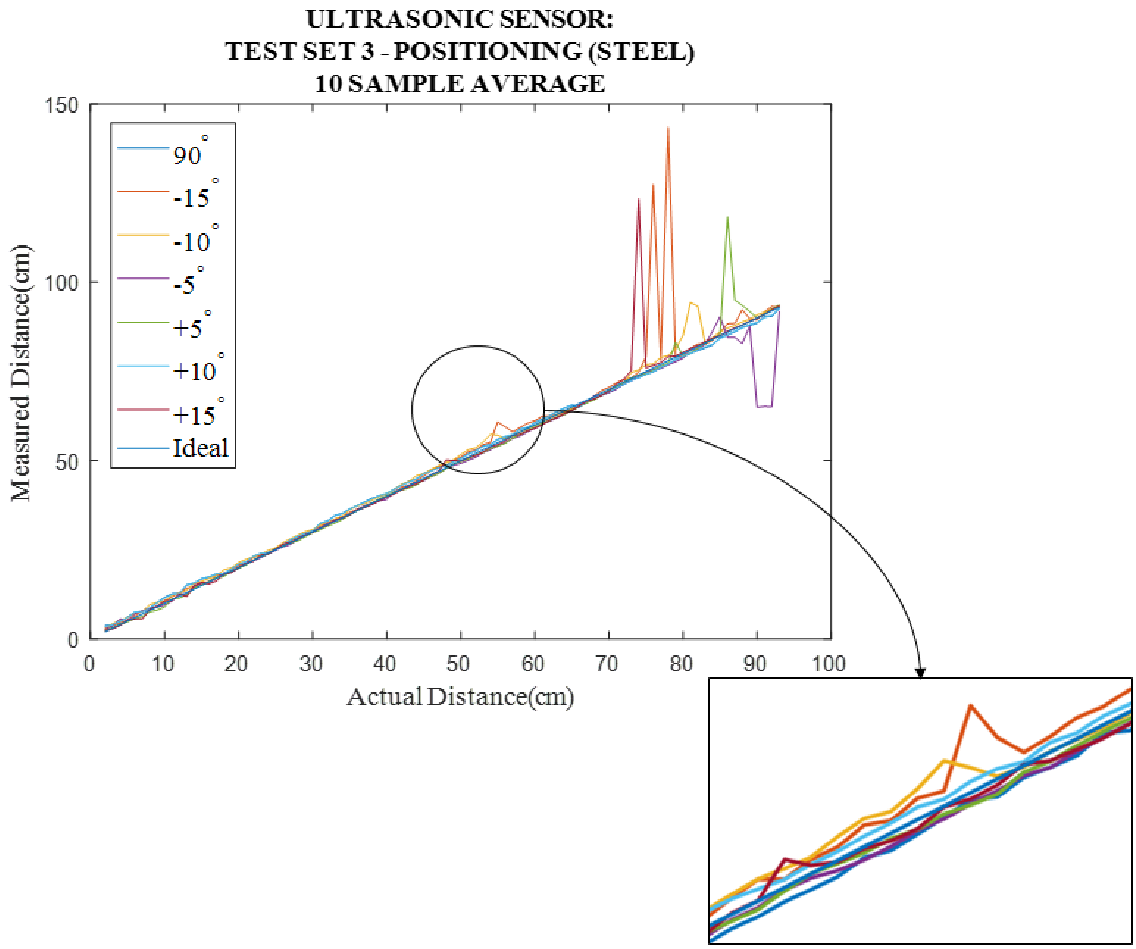

Figure 14 Ultrasonic Sensor - Test Set 3 Plot

CHAPTER 3

3.1 INFRARED SENSOR SIMULATION SETUP, TEST RESULTS, AND ANALYSIS

The measurements for the Sharp IR sensor were taken at 1 cm for the range [10 cm, 80 cm]. The target was placed on the ground and the sensor was leveled with the center of the target's height. Figures 15 to 17 illustrates a sample of the test setup with different views.

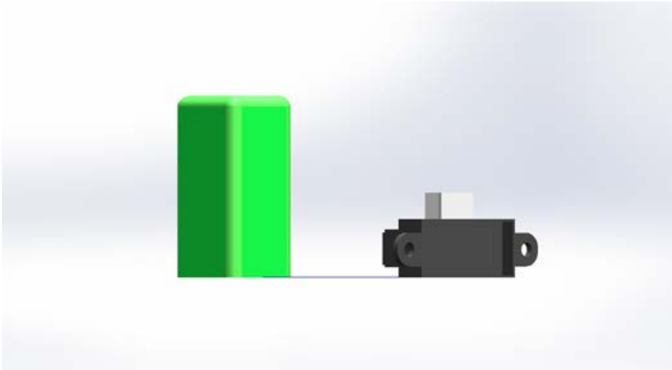

Figure 15 Infrared Sensor Sample Test Setup - Angle View

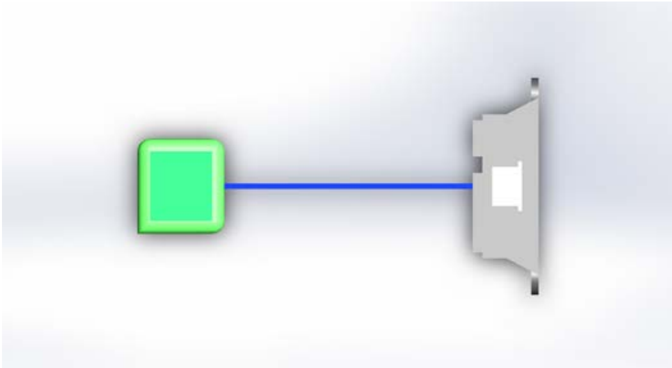

Figure 16 Infrared Sensor Sample Test Setup - Top View

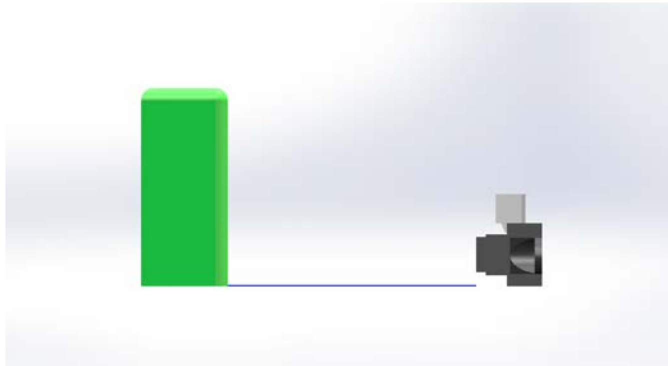

Figure 17 Infrared Sensor Sample Test Setup - Side View

Each test set is performed with all of the filters. Most tests are very similar to those performed with the HC-SR04 ultrasonic sensor in Chapter 2. However, to reduce the amount of flipping pages, the test sets are explained again in this chapter.

Test set 1 exams the performance of the sensor on different target textures. The size and shape of the targets were consistent. The color of the targets is negligible in this test. The target’s environment was consistent and the positioning of the target is set to be at 90° in front of the sensor. The target remained stationary during the measurements.

Test set 2 exams the performance of the sensor on different target sizes. The shape, color, and texture of the target were consistent as well as the target’s environment, positioning, and motion as explained for test set 1. The texture best detected in test set 1 was used as the target’s texture for this test.

Test set 3 exams the performance of the sensor on different target colors. The shape, size, and texture of the target are consistent as well as the target’s environment, positioning, and motion as explained for test set 1. Similar to test set 2, the texture and size best detected by test sets 1 and 2 were used as the target’s texture and size for this test.

3.2 TEST SET 1 – TEXTURE

The variable for test set 1 is the texture of the target. The textures tested were stainless steel, cardboard, construction paper, and glass. Although texture may not entirely affect the Sharp IR sensor, these tests were still performed to compare the results with those found in Chapter 2 of the HC-SR04 ultrasonic sensor. The target's shape, dimensions, and positioning remained consistent throughout the tests, and the target remained stationary as well. Each test case is performed with each of the filtering methods mentioned in Table 1 in Section 1.4.

Using the filter which takes the average of 10 samples, the performance of the sensor on different textures is compared. It is evident in Figure 18 that the stainless steel tray was not detected as well as the glass, paper, and cardboard by the Sharp IR sensor. However, looking at the graphs individually in Figures 19 to 22, it can be concluded that the red paper was detected the best due to the IR sensor's behavior of reflecting more light off of targets of red color. However, it is expected that glass would be detected the worst in comparison to stainless steel, but in reality, stainless steel was not detected the best. Therefore, it can be concluded that texture does not matter as much as color does.

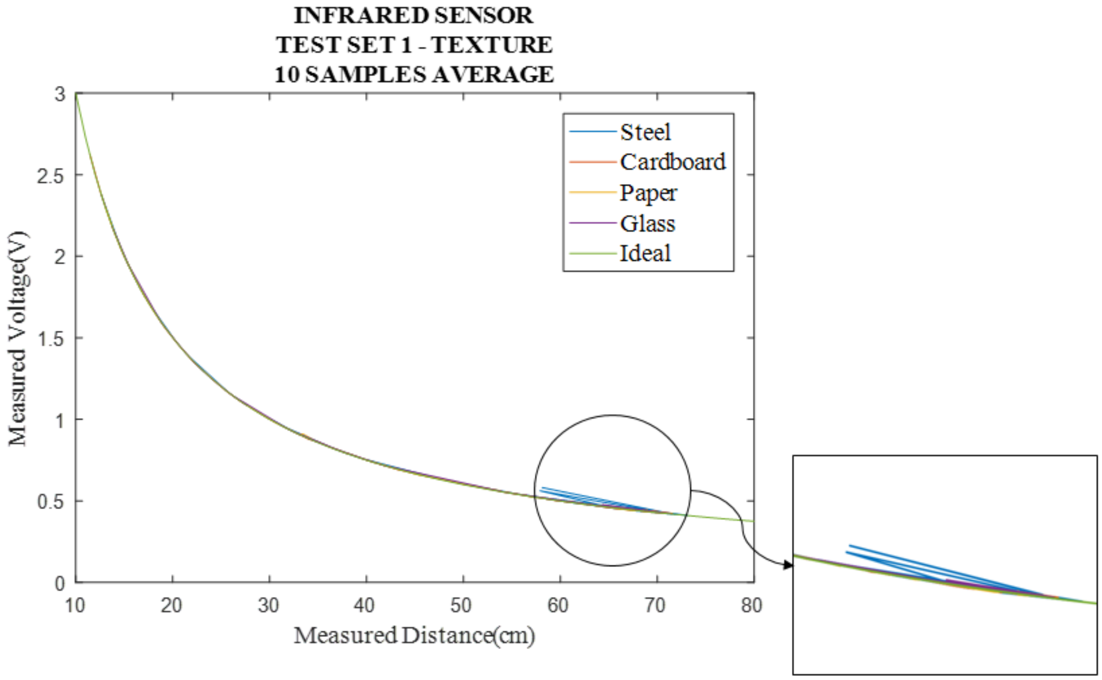

Figure 18 Infrared Sensor - Test Set 1 Plot

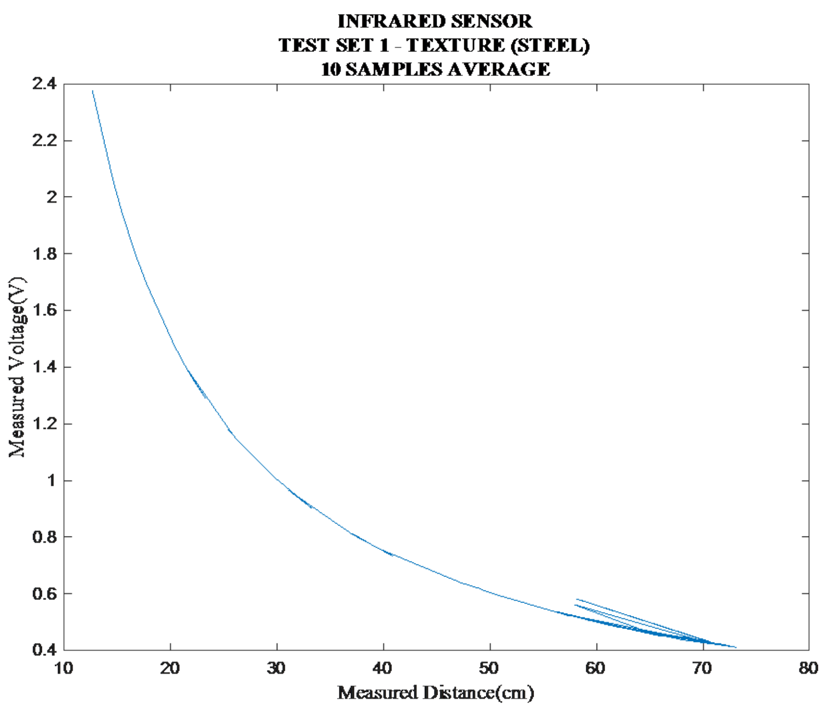

Figure 19 Infrared Sensor - Test Set 1 - Steel Plot

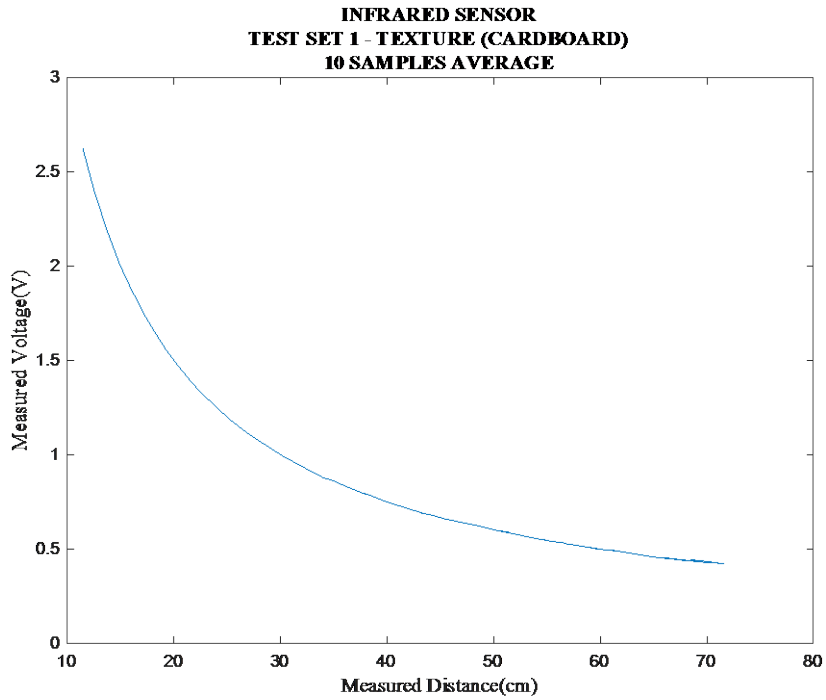

Figure 20 Infrared Sensor - Test Set 1 - Cardboard Plot

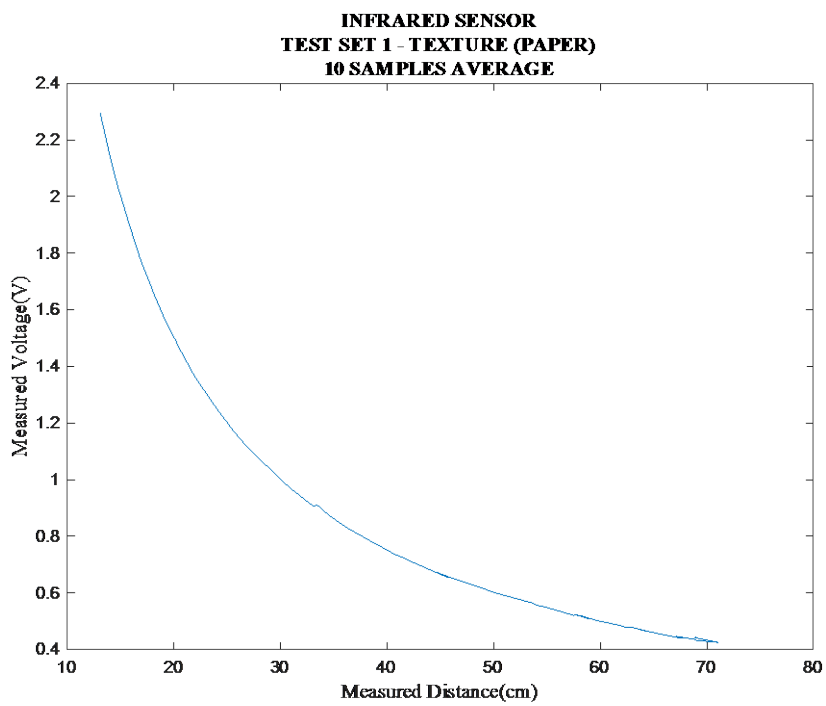

Figure 21 Infrared Sensor - Test Set 1 - Paper Plot

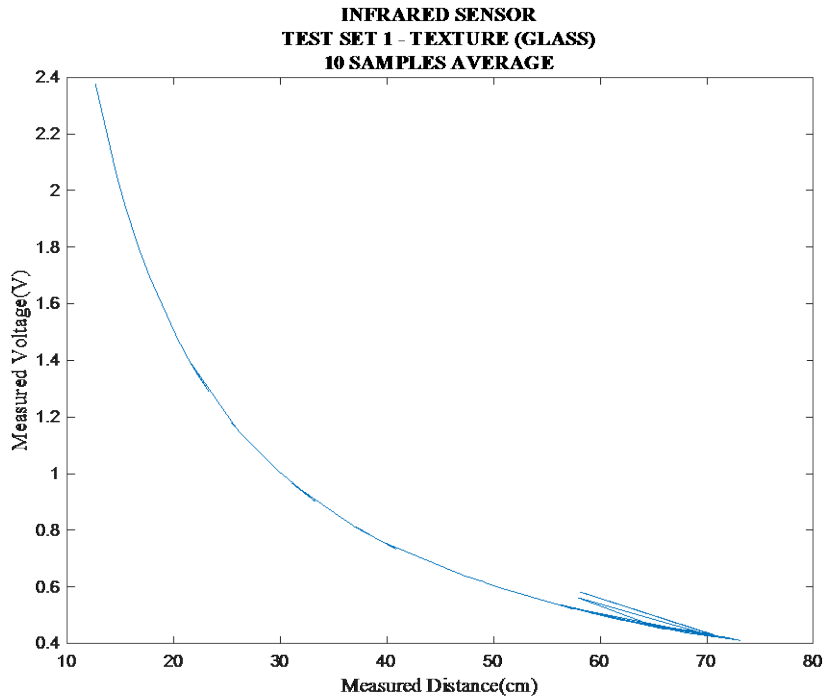

Figure 22 Infrared Sensor - Test Set 1 - Glass Plot

3.3 TEST SET 2 – SIZE

The variable for test set 2 is the size of the target. Two sizes were tested: small and large. The larger size had been tested in test set 1. Each test case is performed with each of the filters mentioned in Table 1 in Section 1.4. Red construction color was the texture and color used since it was best detected in test set 1. The targets were positioned at 90° in front of the sensor and remained stationary throughout the tests.

Using the filter that takes the average of 10 samples, the performance of the sensor on the different sizes is compared. As it can be seen in Figure 23, the smaller sized red paper was not detected as well as the larger sized red paper. One reason may be that the smaller size, the smaller the area, the larger chance of the sensor's light to be reflected off of other surrounding objects.

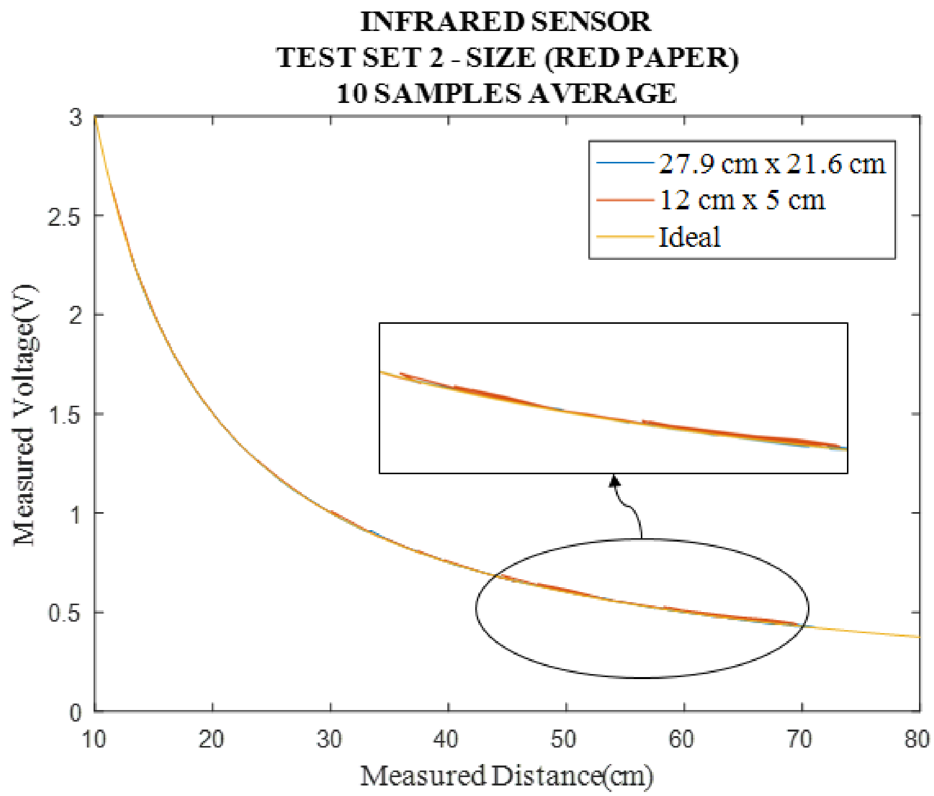

Figure 23 Infrared Sensor - Test Set 2 Plot

3.4 TEST SET 3 – COLOR

The variable for test set 3 is the color of the target. Red, black, and white were the colors tested since the red construction paper was best detected by the IR sensor. Each test case was performed with all of the filters mentioned in Table 1 in Section 1.4.

Using the filter that takes the average of 10 samples, the performance of the sensor on different target colors is compared. As shown in Figure 24, the black paper had a misreading from the sensor although all three colors yielded similar results overall. The black paper had this issue due to the characteristic of the color black in the IR spectrum. Black absorbs most of the light while colors like white and red reflect most of the light.

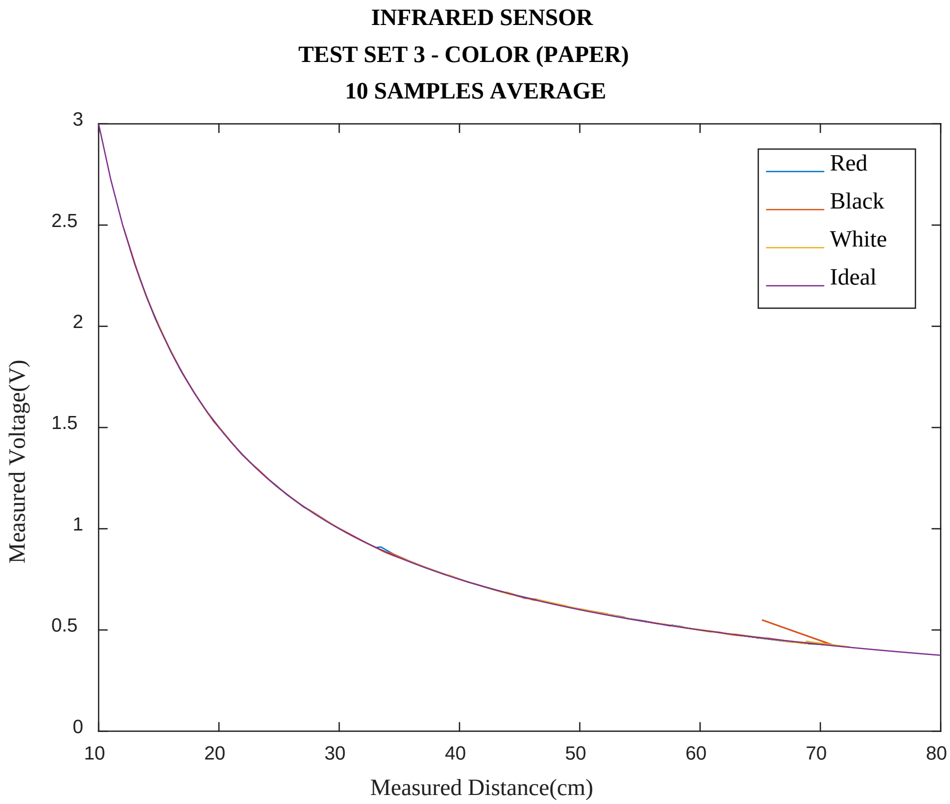

Figure 24 Infrared Sensor - Test Set 3 Plot

CHAPTER 4

4.1 FILTER ANALYSIS, SENSOR COMPARISON, AND OPTIMUM SOLUTIONS

This section analyzes the results of the different filters obtained from the tests performed using the HC-SR04 ultrasonic sensor and the Sharp IR sensor. The most optimum solution is then suggested. It is important to note that the test supplies were setup such that the most optimum results were obtained. For example, it was possible to place the sensor on the ground. However, this would yield more inaccurate results as shown in Figure 25, which shows the results of a previous test performed using cardboard. This was due to the sensor detecting the ground at certain times.

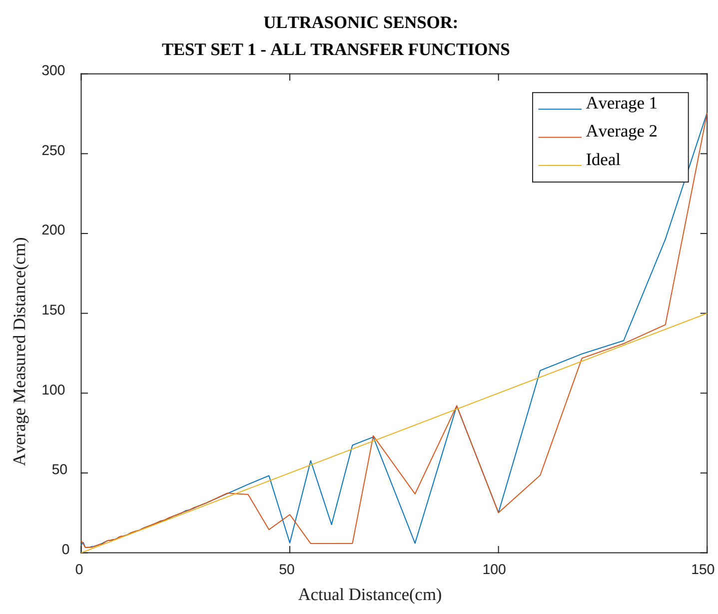

Figure 25 Previous Test Graph - Cardboard Box

The performance of the different filters is examined on the glass tray target, the 12 cm by 5 cm stainless steel tray and the stainless steel tray positioned at -15° with respect to the sensor. Figure 26 shows the performance of the sensor with the glass tray as the target using different filters. It illustrates that the 10 and 5 sample filters which removed the minimum and maximum values of the sample list then took the average yielded better results at certain points of the measurements. However, the different filters did not have a drastic effect on the results overall. Rather the texture of the target was what controlled the outcome of the HC-SR04 sensor readings.

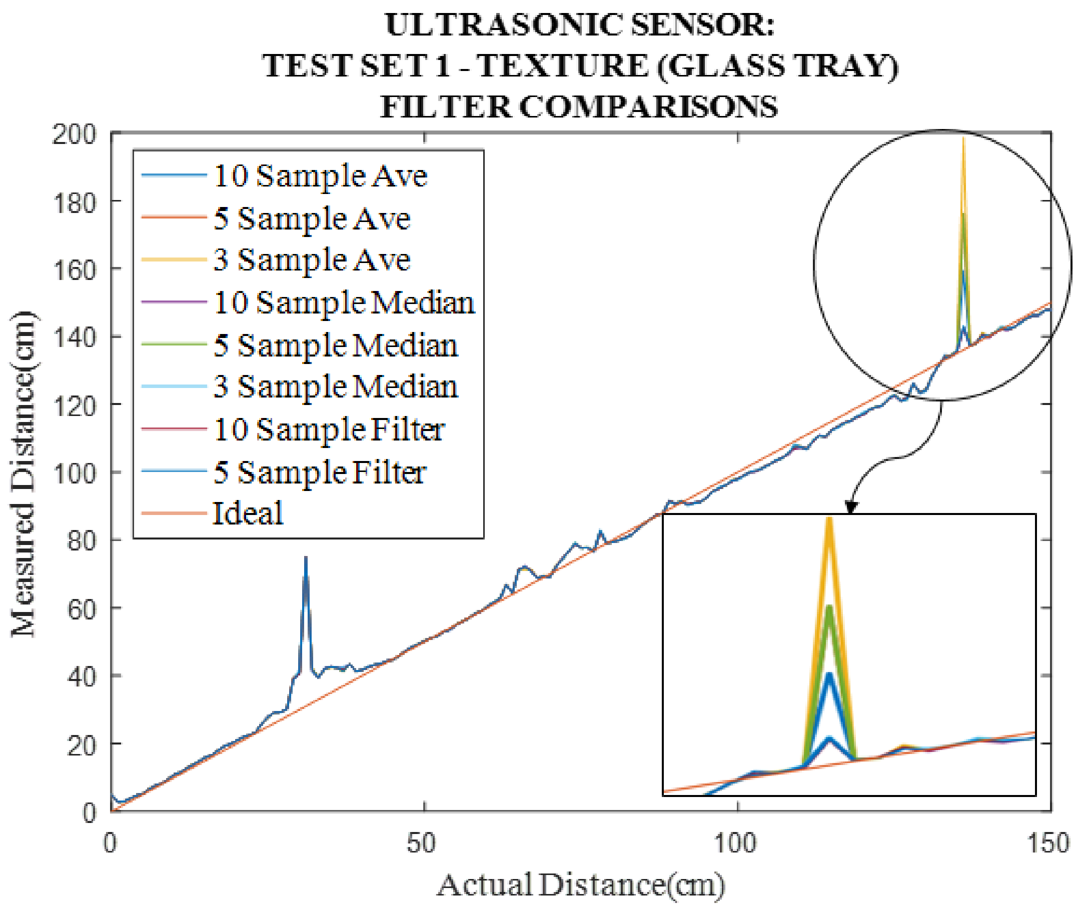

Figure 26 Ultrasonic Sensor - Test Set 1 - Filter Comparisons Plot

Figure 17 shows that the median filters yielded better results for the smaller sized stainless steel tray in comparison to other filters. This suggests that different filters do not have the same performance on different targets and scenarios.

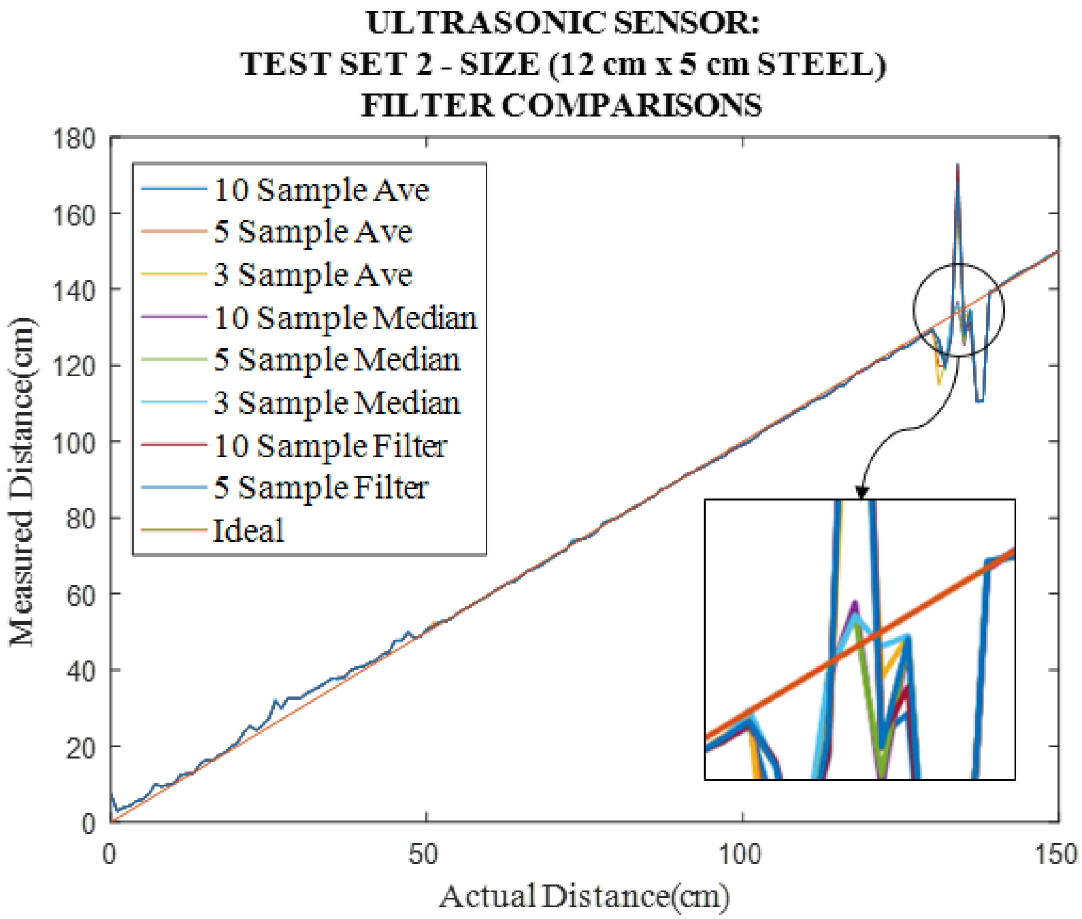

Figure 27 Ultrasonic Sensor - Test Set 2 - Filter Comparisons Plot

Lastly, Figure 28 compares the filters on the -15° position of the stainless steel (35.5 cm by 26 cm) target with respect to the sensor. It illustrates that quite a few of the filters yielded similar and improved results on the sensor. However, no trend was observed between the three targets and scenarios, which suggests different filters have different effects.

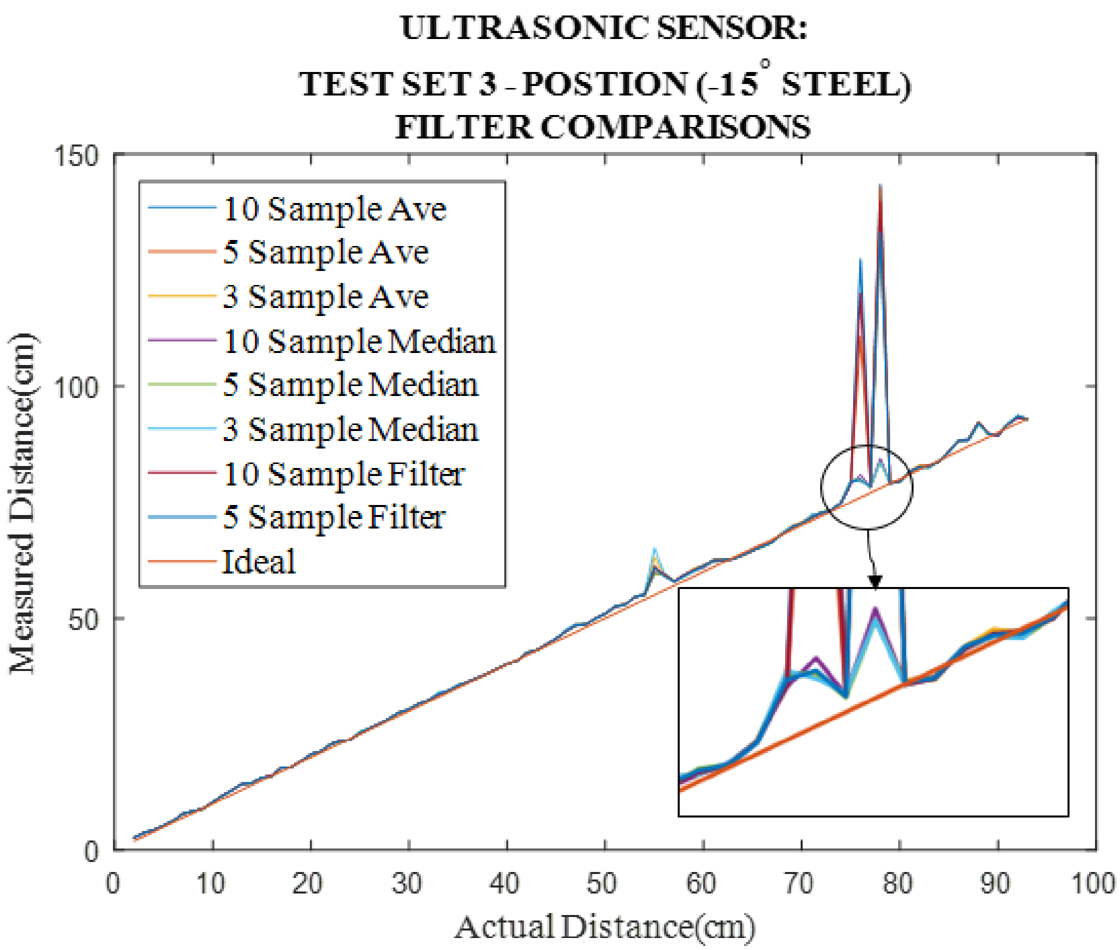

Figure 28 Ultrasonic Sensor - Test Set 3 - Filter Comparisons Plot

It is important to note that the filters were not compared with the Sharp IR sensor's outputs since the Sharp IR sensor's results were fairly accurate in comparison to the HC-SR04 ultrasonic sensor's results. It is observed that the filters did not yield consistent results for all test cases. Therefore, the optimum solution found was not the type of filter to use rather the position of the sensor with respect to the target and its surroundings. As mentioned in Chapter 2, the sensor was leveled with the center of the target where in previous tests performed (results not included in this thesis) the sensor was placed on the ground. The sensor was placed on the ground, it generated more random distance readings as opposed to the sensor being leveled at the center of the target that resulted in more accurate distance readings.

Furthermore, the first filter, which removes any readings beyond the acceptable range of the sensor, was initially not included and more random readings were observed. Distance measurements such as 1376 cm was observed for the HC-SR04 ultrasonic sensor although the datasheet specifications mentioned the possible range of detection is 0 cm to 400 cm. Table 2 is from a set of trials previously performed that were not included in this thesis but it serves to illustrate the observation made earlier.

35	37.28	37.69	37.29	37.28	37.28	37.364
40	3170.53	6.59	3175.45	6.57	3189.98	1909.824
45	6.69	268.48	268.03	267.5	3204.28	802.996

Table 2 Example - Snippet of Previously Ran Trial

Therefore, an initial filtering of the results is required to obtain better readings as well. However, for the second set of filters which were used to optimize the accuracy of the sensor data, the performance change observed was very minimal.

Lastly, the Sharp IR sensor yielded more accurate results in comparison to the HC-SR04 ultrasonic sensor although the effective range of measurement for the Sharp IR sensor is only 10 cm to 80 cm while the HC-SR04 ultrasonic sensor had a longer effective range. However, if the range of the HC-SR04 ultrasonic sere from 10 cm to 80 cm is to be compared with the Sharp IR sensor, then it can be observed that both yield consistent results within that range.

CHAPTER 5

5.1 CONCLUSION

To conclude this thesis, a proposal of future work to be performed is discussed. Although multiple filters exist for data image processing and signal processing, not all of them optimize the accuracy of the ultrasonic and infrared sensors, namely, the HC-SR04 and Sharp GP2Y0A21YK, respectively, as observed in earlier chapters. Thus, the design of a new filter to optimize the performance of these specific sensors is highly suggested. Different sampling rates and numbers should be tested and different statistical operations should be performed in order to obtain the optimal filter to improve the accuracy of the sensors.

NOMENCLATURE

FPGA Field Programmable Gate Array

IR InfraRed

ITS Intelligent Transportation System

VANET Vehicular Ad hoc NETworks

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