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Performance comparison of Infrared and Ultrasonic sensors for obstacles of different materials in vehicle/ robot navigation applications

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Abstract – In robotics, Ultrasonic sensors and Infrared sensors are commonly used for distance measurement. These low-cost sensors fundamentally address majority of problems related to the obstacle detection and obstacle avoidance. In this paper, the performance comparison of ultrasonic and infrared measurement techniques across obstacles of different types of materials presented. The Vehicle model integrated with the sensors, moving with constant velocity towards different types of obstacles for capturing the distance parameter. Based on the data acquired from the sensors, correlation analysis of the measured distance with actual distance performed. This analysis will be very much useful, to select the right sensor - Ultrasonic sensor / Infrared sensor or a combination of both sensors, while developing the algorithm for addressing obstacle detection problems. The detection range and inherent properties of sensors (reflection/ absorption etc.) also were tested in this experiment.

1. INTRODUCTION

In robotics, ultrasonic (US) and infrared (IR) sensors are widely used for contact-less, mid-range distance measurements in navigation systems for humans, mobile robots and vehicle related applications. Obstacle detection is one of the challenging problems in the navigation systems. There are obstacles made of different types of materials, in which the performance of the distance measurement sensor varies. This paper showcases the performance analysis of the US and IR sensors for the obstacles made of different type of materials such as cardboard, paper, sponge, wood, plastic, rubber and tile. The ultrasonic sensor uses time of flight (TOF) method for distance measurement, which refers to the time taken for a pulse to travel from the transmitter to an observed object and back to the receiver [1]. The Infrared sensor works based on the detection of a specific light of wavelength in the range of 760nm (IR spectrum), which is emitted by an IR Light Emitting Diode (LED). The distance can be measured based on the change in intensity of the received light. For the IR sensor, colour of the obstacle material could also affect the reading of the sensor [12]. For addressing the navigation problems in robotics, various soft computing techniques such as Fuzzy Logic, Neural networks etc were successfully employed [13,14,15]. Typical navigation systems use the above sensors for both obstacle detection and obstacle avoidance problems [16]. The features such as light weight, robustness, cost effectiveness, quicker responsive time etc., make the sensors widely acceptable in all the domains. It is highly important to choose the best sensor for capturing the distance data for different types of obstacles. The analysis performed in this paper will provide some guidelines to select the right sensor for a given type of obstacle.

The structure of the paper as follows: Section.2 describes the sensor characteristics of sensors used, Section.3 deals with the experiment setup and procedure used, Section.4 for Results & Discussion and Section.5 for conclusion.



2. SENSOR CHARACTERISTICS

Sensor selection is a challenging task for any system design, as it critically affects the system performance and its lifetime. The ultrasonic sensor (HC SR-04) and infrared (SHARP GP2Y0A21YKOF) are the sensors selected for the analysis, because of its better cost-performance ratio. Table 1 shows the technical specification of the sensors. The ultrasonic sensor (US) is largely accepted for addressing the challenges in mapping and localization. The sensor emits high-frequency sound wave (40 kHz) through one of its piezo- electric transducers and detects the returning pulses (echo) in the air through another transducer and converts it to proportional voltage variation [2].



Figure 1. HC-SR04 Ultrasonic Sensor

The piezoelectric sensor accepts triggering pulses from the microcontroller and send the echo-detection pulses back to the microcontroller. Figure 1 shows the ultrasonic sensor used for the experiment. The beam shape of the sensor is conical and the width of the beam is a function of the surface area, frequency and type of transducers used. The beam spread at maximum sensitivity is 38 inches across at 10 ft. away from the sensor [18]. The sensor can detect all types of obstacles such as metal, wood, concrete wall, plastic etc., with an extremely less affinity with the lighting conditions [3]. The velocity of the ultrasonic wave travel in the air is usually affected by the parameters such as ambient noise, temperature, humidity. In addition, it is more sensitive to the mirror like surfaces [4]. Because of this, for an effective detection of an object with reflexive nature, it to be brought into a position, that is normal to the sensor acoustic axis [5].

The infrared (IR) sensor offers a high resolution with quicker response time, compared with the ultrasonic sensors [6]. The infrared distance measurement sensor works on the principle of optical triangulation [7]. The IR sensor used for the experiment is shown in figure 2. Sharp infrared sensor has an IR transmitter and a position sensitive device. The position sensitive device is an optical detector which can detect the light falling on a plane. By processing the signal from position sensitive device and interpreting the signal gives the distance of the obstacle in front of it. Figure 4 provides the interpretation of analog value from the sensor with distance. [8]



Figure 2. SHARP GP2Y0A21YKOF Infrared Sensor

As the sensors exhibits non-linear characteristic across various surfaces, it is required to interpret the sensor outputs as the distance measure [9]. From the distance measurement characteristics, it is inferred that the IR sensor can provide an inconsistent reading for an obstacle with proximity less than 5cm. The analysis of reflection coefficient of IR sensor also a one of the popular method to identify the type of obstacle [12]. Both ultrasonic and infrared sensors provides the better environment perception (advantage of one sensor compensate the disadvantage of other) for the smooth navigation of the vehicle model [11,17]. Table 1 indicates various parameters associated with the sensors for the experiment setup.

Table 1. Technical Specification of Sensors

Parameters	IR Sensor (SHARP GP2Y0A21YKOF)	Ultra Sonic Sensor (HC SR-04)
Range	10cm-80cm	2cm-10m
Beam-width	75 Deg.	30 Deg.
Beam Pattern	Narrow (line)	Conical
Frequency	353 THz	40 KHz
Unit Cost	~ 750 INR.	~ 130 INR.

3. EXPERIMENT SETUP AND PROCEDURE

The experiment was conducted on moving the vehicle model (30cm x 16.6cm x 6cm) equipped with ultrasonic sensor, infrared sensor and rotary wheel encoder (shown in figure 3a) against the obstacle with a fixed velocity. The model uses a 7.2V, 3000mAh rechargeable Ni-Cd battery, as the power source. DC and servo motors acts as actuators for drivetrain and steering systems respectively. Using this model, the steering wheel geometry (Ackerman Steering system) can also be tested.

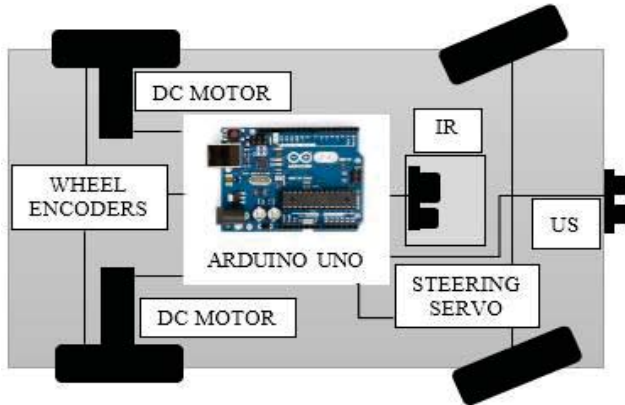


Figure 3a. Block diagram of experiment setup



Figure 3b. Photograph of Experiment setup

The data from the US and IR sensors, for different types of obstacles were acquired by an Arduino Uno microcontroller unit and is logged to the PC for interpretation. The sensors were directly connected to the controller, without any interfacing electronics. The photograph of the vehicle model is mentioned in figure 3b. Though the model uses a set of ultrasonic sensors along with an IR sensor, the experiment recorded the data only from Two sensors (US and IR) located at the front side of the vehicle.

The distance travelled (D) by the vehicle model (actual distance) is measured using a rotary encoder attached near to the tyres of the vehicle model. A rotary encoder is a small disc with holes placed at equal intervals. An IR diode is placed to one side of the disc and a detector at the other side, both in line of sight. As the vehicle moves, disc rotates, and based on the intervals of detection, the distance travelled by the vehicle model can be calculated. The sensor data, which is acquired in real-time is compared with D for the analysis. Error percentage can also be found using this method.

4. RESULTS AND DISCUSSION

The materials selected for the analysis were Cardboard, Paper, Sponge, Wood, Plastic, Rubber and Tile. The parameters 'Measured Distance' and 'Actual Distance' (in centimeter scale) will provide an insight into the performance of sensors over the specified materials. The difference in the distances provides the 'Error' for both sensors. The statistical analysis presented at the end of this section will be useful for the selection of the right sensor for a given obstacle type. The details of the analysis as follows;

4.1 Obstacle Material: Cardboard:

Cardboard, a fibrous material which processes a minimum of 0.30 millimeter or more in thickness, which is commonly made from wood pulp, straw, wastepaper, or a combination of these materials. The Ultrasonic Sensor provides a steady reading only after 15cm, because of the reflective surface of the material. From figure 4, it can be observed that measured value is slightly greater than the actual one, because of the absorption of sound waves. The performance of IR indicates the minimum range (10 – 15cm) of detection of obstacle. Ultrasonic Sensors are the right choice for such type of obstacle.

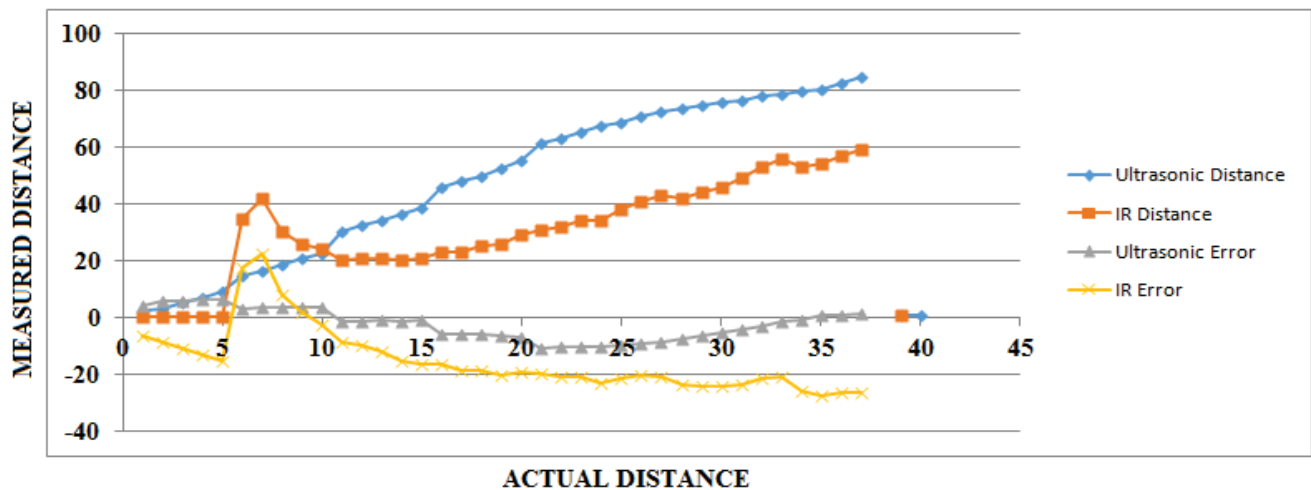


Figure 4. Plot (Measured Vs Actual distance)

4.2 Obstacle Material: Paper Sheet

Figure 5 indicates the response of both the sensors for such type of obstacles. As the surface of paper is smooth and reflects the infrared light falling on it, IR shows a steady response within its range. The ultrasonic sensor reading shows an enormous variation, because of the transmitting property of sound by paper. The paper (sheet) allows the sound pulses to pass through it and the result obtained clearly indicates the same. Infrared sensor best suits for this kind of obstacle.

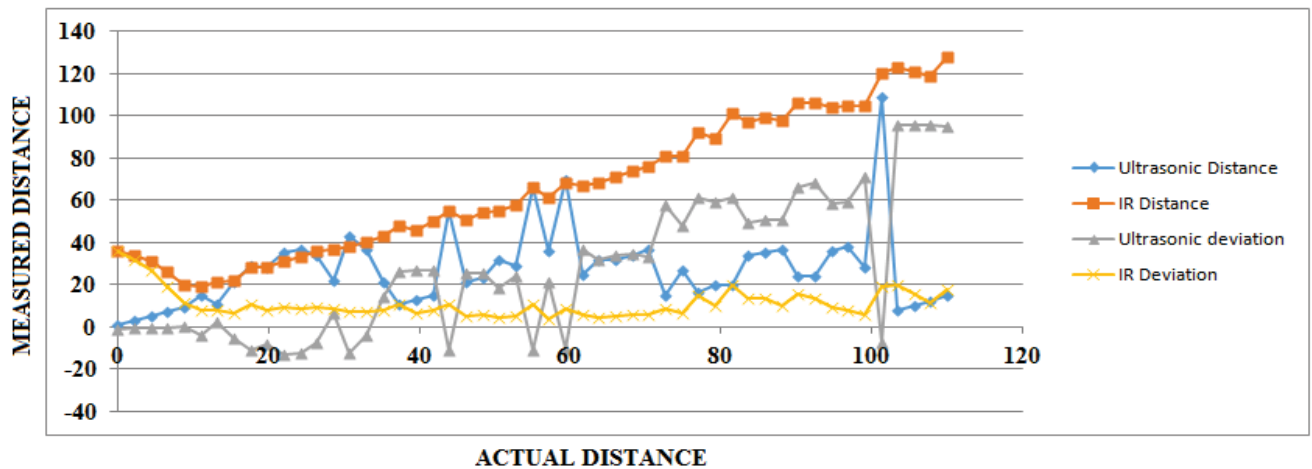


Figure 5. Plot (Measured Vs Actual distance)

4.3 Obstacle Material: Sponge

The sponge reflects negligible signal falling on it and transmits most of the signal due to its void nature and that is the reason behind the steady response of US, with an offset. The Infrared Sensor shows a steady reading, with minor deviations due to reflection of infrared light on non-perpendicular surface. Figure 6 shows the characteristics of the sensors for the medium. IR sensors are the right choice for these type of obstacles.

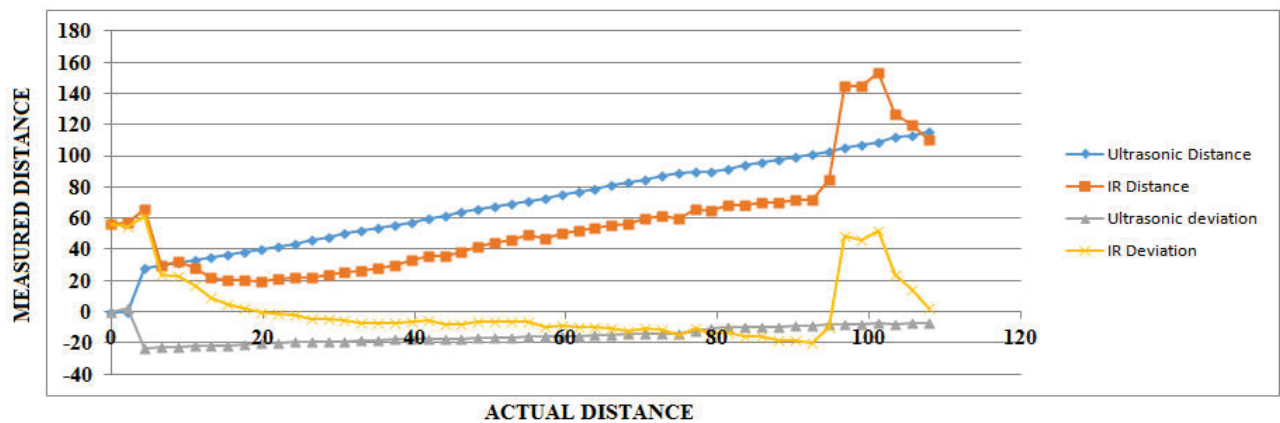


Figure 6. Plot (Measured Vs Actual distance)

4.4 Obstacle Material: Wood

Figure 7 shows a steady reading for Ultra Sonic sensor as wood is has a rough surface and reflects good amount of sound energy for the sensor to detect. The infrared sensor shows a huge deviation in the lower range and an offset. This is because, at lower range, the sensor reflection is taken for a large distance. The deviations in reading is because of non-smooth surface for reflection of light. Ultrasonic Sensors are the right choice for such type of obstacle.

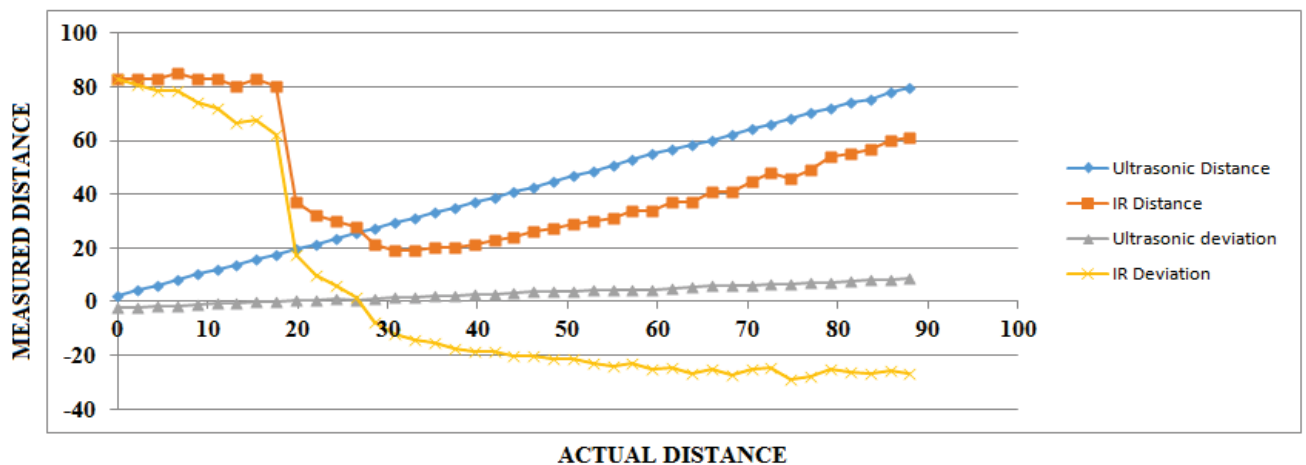


Figure 7. Plot (Measured Vs Actual distance)

4.5 Obstacle Material: Plastic

The reading from ultrasonic sensors is more stable and linear, as per figure 8. This is because, the surface of plastic is smooth and it is rigid, which reflects most of the sound waves falling on it. The infrared sensor shows a large deviation from the actual one, as the plastic is transparent, compared with other obstacle types and it transmits most of the light falling on it. In addition, the double refraction also affects the sensor reading. Ultrasonic Sensors are the right choice for such type of obstacle.

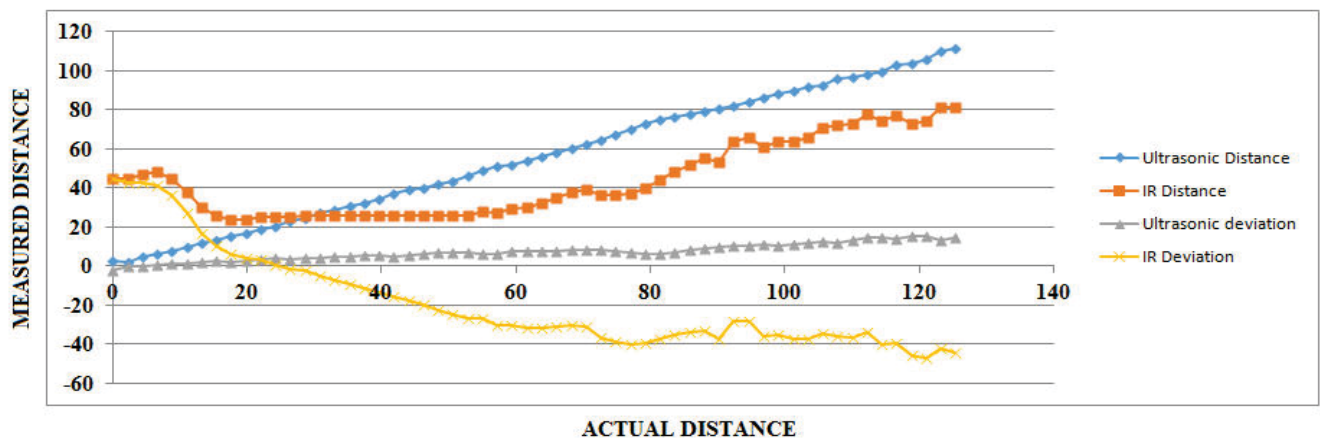


Figure 8. Plot (Measured Vs Actual distance)

4.6 Obstacle Material: Rubber

Figure 9 indicates the ultrasonic sensor reading for rubber is quite linear. This is because of the elastic nature of rubber, which reflects most of the sound signal falling on it. The infrared shows a few deviations due to non-smooth reflecting surface of the rubber sample. Ultrasonic Sensors can be used for such type of obstacles.

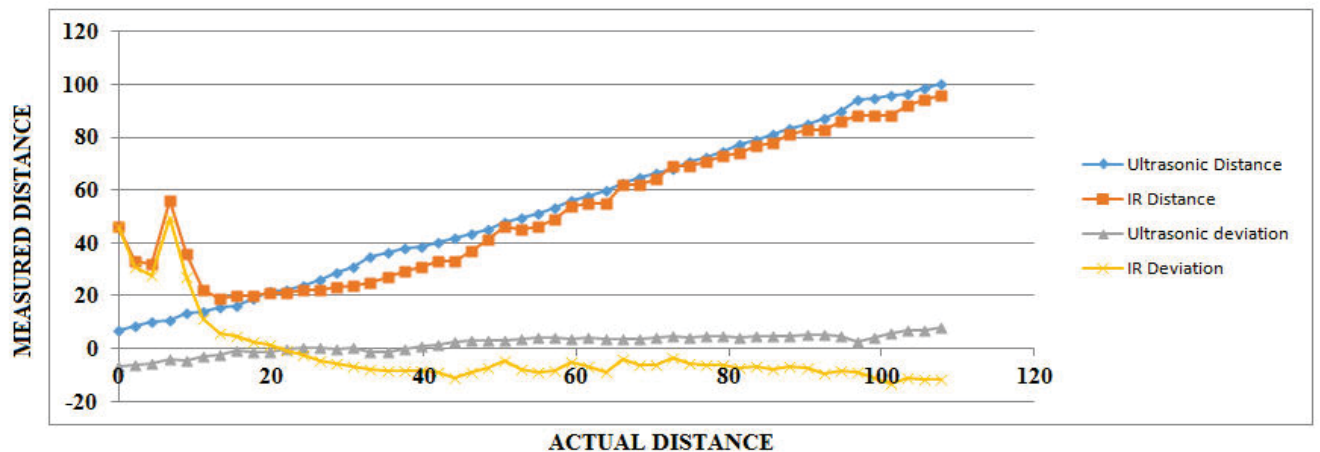


Figure 9. Plot (Measured Vs Actual distance)

4.7 Obstacle Material: Tile

Figure10 shows the ultrasonic sensor readings are linear and smooth. This is because; the tile is rigid and reflects sound. The infrared sensor has small deviation and large offset because of the irregular surface leading to different angle of reflection. Both Ultrasonic and Infrared sensor can be used, but with a slight prominence to the Ultrasonic Sensor for similar kind of obstacle.

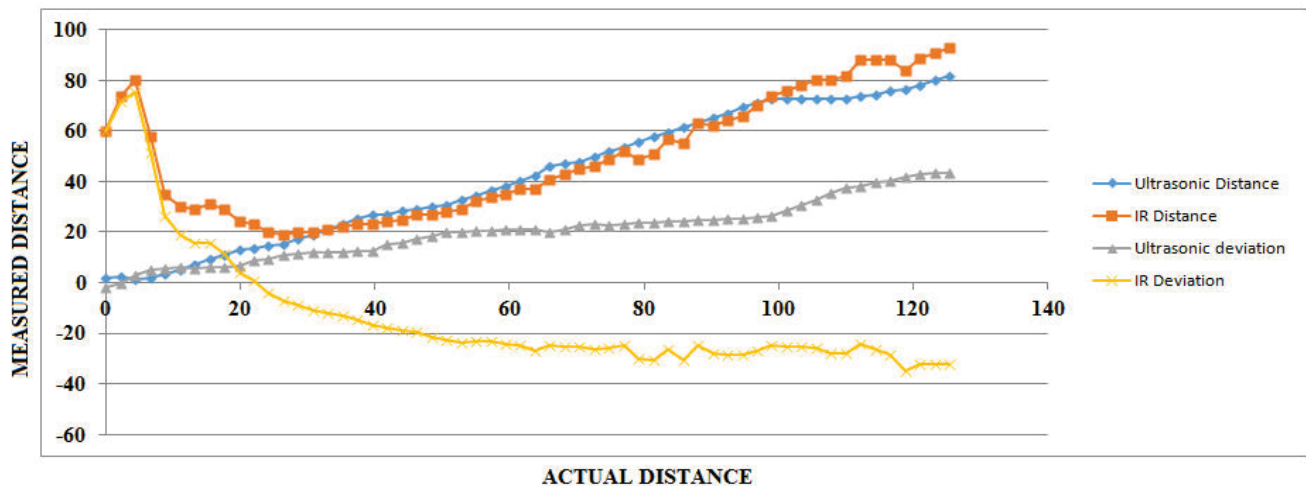


Figure 10. Plot (Measured Vs Actual distance)

The objective of this experiment was to perform a comparison of IR and ultrasonic sensor against various types of obstacles. The statistical analysis of the sensor data against various types of obstacles is shown in Table 2. The correlation coefficient (r) was estimated between measured and actual distance values as well as IR-US sensor readings for the analysis. The standard deviation parameter (for individual sensor data set) also considered, to check the consistency of the sensor measurement for a specific type of obstacle. The benchmark set for the readings were; 0.9 and above – Very High correlation, 0.7-0.9 – High Correlation, 0.5-0.7 - Medium correlation, 0.3-0.5 - Low correlation and 0.3 or lesser – Negligible correlation.

Table 2. Statistical analysis of sensor data for different obstacle materials

Material	Ultrasonic Sensor		Infrared Sensor		(r) (US-IR)
	<i>Std. Dev</i>	<i>r</i>	<i>Std. Dev</i>	<i>r</i>	
Cardboard	9.3	0.9879	10.6	0.91089	0.88424
Paper Sheet	37	0.2611	20.2	0.97866	0.20663
Sponge	5.8	0.9868	21.6	0.78774	0.72976
Wood	10	0.9999	36.5	-0.3291	-0.3285
Plastic	4.3	0.9995	25.1	0.78681	0.78767
Rubber	4.6	0.9988	58.3	0.90998	0.9216
Tile	11	0.9952	23.8	0.73032	0.73085

From Table 2, the following observations can be made;

1. Ultrasonic sensor can perform well for the obstacle types such as Sponge, Wood, Plastic and Tile.
2. Combination of Ultrasonic and Infrared sensors can be used for the obstacle types Cardboard and Rubber. The correlation coefficient indicates a 'High' correlation between the sensor data.
3. Infrared sensor can perform better for the obstacle of type 'Paper sheet'.

5 CONCLUSION

The vehicle model equipped with the distance measurement sensors provides a right platform for capturing the real-time data. The statistical analysis of the distance data (measured distance) from sensors with the actual distance will certainly help select the right sensor for the given type of obstacle. Correlation value indicates the performance of ultrasonic sensors for a good set of obstacle types and infrared sensors to a specific type of material. The low cost sensors used for the analysis also helps the cost effective development of better algorithms for addressing the navigational problems. The accuracy on the data can be achieved by the use of necessary hardware/software filters. Further, by using necessary signal processing techniques, the sensor data quality may be enhanced. Applied soft computing techniques such as neural networks, fuzzy logic also will enhance the quality of the data set to a greater extent.

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