Ultrasonic and Infrared Sensors Performance in a Wireless Obstacle Detection System

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***Abstract* – Ultrasonic (US) and infrared (IR) sensors are broadly used in mobile applications for distance measurements. In this project, an obstacle detection system is built based on these two types of sensors. The system is intended for use by the elderly and people with vision impairment. The prototype developed has been tested to detect obstacles and shows accuracies of 95% to 99% for distance measurements if the sensor circuits are calibrated properly and their output linearized. The system also demonstrates good detection for different obstacle materials (e.g., wood, plastic, mirror, plywood and concretes) and colors. The minimum size of an obstacle that the system can detect is 5 cm x 5 cm.**

Keywords*– *obstacle detection system, ultrasonic sensors, infrared sensor

I. INTRODUCTION

Ultrasonic (US) and infrared (IR) sensors are frequently used for mid-range distance measurements. Typical applications of these sensors include navigation systems (human, mobile robot and vehicles) as obstacle avoidance, distance measurement, counting devices (e.g., wait watcher, product assembly), surveillance system, object detection, edge detection and military applications [1-3]. Robustness, lightweight, inexpensive and fast response time makes these sensors suitable to be used in the development of navigation aids.

In addition, the ability to gather information about the scene of action, mapping and localization, make the ultrasonic sensor suitable in detecting the obstacles [4]. Furthermore, a ultrasonic sensor can detect all types of obstacle (e.g., metal, wooden based object, concrete wall, plastics, rubber based product, transparent object, etc.) and it is not affected by poor lighting condition [5].

However, the velocity of ultrasonic wave travel in air is affected by environmental parameters such as temperature, humidity and appearance of ambient noise. Nevertheless, US sensors have limitations due to their wide beam-width and sensitivity to the mirror-like surfaces [6]. Because of having the properties of a mirror, only reflecting objects that are almost normal to the sensor acoustic axis may be accurately detected [7]. Alternatively, infrared sensors can be used in obstacle detection because of their high resolution, low cost and faster response times compared to ultrasonic sensors [8]. However, these sensors have non-linear characteristics and they depend on the reflectance properties of the object surfaces. Therefore, knowledge of the surface properties must be known beforehand. In other words, the nature in which a surface reflects and absorbs infrared energy is needed to interpret the sensor output as distance measure [9]. The distance estimation could be obtained by using Phong Illumination model [10].

The time of flight (t_{of}) method is a preferred choice for distance measurements when using contact-less sensor (US and IR). In distance measurement technique, t_{of} is refers to the time it takes for a pulse of energy to travel from its transmitter to an observed object and back to the receiver. The energy of transmission might come from several sources such as ultrasonic, light or radio. The distance is determined by multiplying the velocity of the received energy pulse by the time required to travel the distance [11].

The US and IR sensors are utilized in this work to create a complementary system that is able to give reliable distance measurement [12]. They can be used together where the advantages of one compensate for the disadvantages of the other. This paper describes an obstacle detection system using US & IR sensors. The paper structured as follows: Section II highlights the selection criteria of sensor, and section III describe the structure and methodologies used for each sensor. Section IV demonstrates the results and discussion where the conclusion and recommendations are specified in section V.

II. SELECTION CRITERIA OF SENSORS

Sensor selection is a crucial activity to be considered in any system design, as it will make a great impact on the process of the system performance during its entire lifetime and could even has consequences related to the quality of the product. The ultrasonic (Maxbotics LV EZ1) and infrared (Sharp GP2Y0A02YK0F) sensors were chosen in this research because of their high resolution, robustness, lightweight and low cost. The use of these sensors also provides a better cost-performance ratio compared to other sophisticated imaging systems, such as the ones based on stereo vision camera, GPS or laser scanning. Table 1 summarizes some technical specifications of the sensors used in this research [13-14]. In this research the size and weight of the sensors and their interfaces to a

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microcontroller are of paramount importance, because the sensors will be installed on the front of the shoes of the user.

TABLE 1 Technical specification of the sensors

Sensor	MaxSonar LV EZ1	Sharp GP2Y0A02YK0F
Range	0.15 – 6.45m	0.2-1.5m
Resolution	2.54cm	1cm
Beam Width	± 30°	10°
Weight	4.3g	4.8g

Figures 2 and 3 show the simple interfaces required for the connection of the US and IR sensors to the microcontroller.

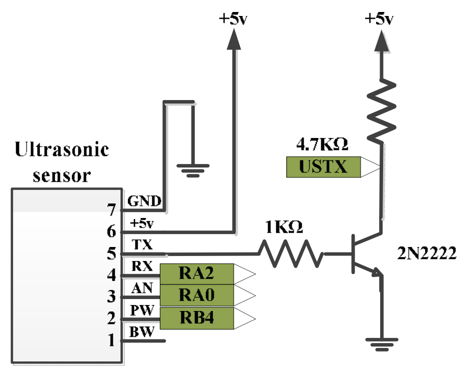

Fig. 2 The connection of the US sensor to the microcontroller

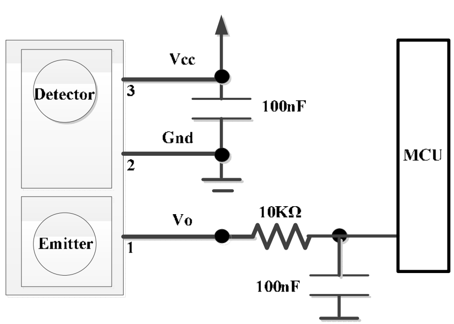

Fig. 3 The connection of the IR sensor to the microcontroller

III. SYSTEM STRUCTURE AND METHODOLOGY

The prototype of the system is shown in Figure 5. The system can be divided into two parts, which can be considered as transmitter and receiver. The transmitter part contains of sensors (IR and US), conditioning circuit, microcontroller and RF wireless Tx modules 433 MHz. The receiver part consists of RF wireless Rx modules 433 MHz, microcontroller and alarming units (e.g., buzzer, vibrator and audio module).

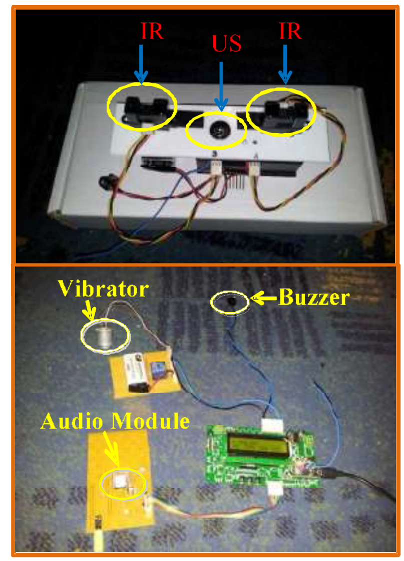

Fig. 5 The prototype components

Trigonometry functions are used to determine the distance between the user and obstacle using ultrasonic sensor; however, triangulation and Phong Illumination model are the popular methods to measure a distance between the user and obstacle for infrared sensors.

A. Ultrasonic measurement principle

The ultrasonic sensor radiates a pulse signal, S_T to the object and then receives a reflection signal, S_R back to sensor. The distance will be measured by calculating the reflection time interval between the target and sensor [15]. The ultrasonic measurement technique can be illustrated in Figure 4.

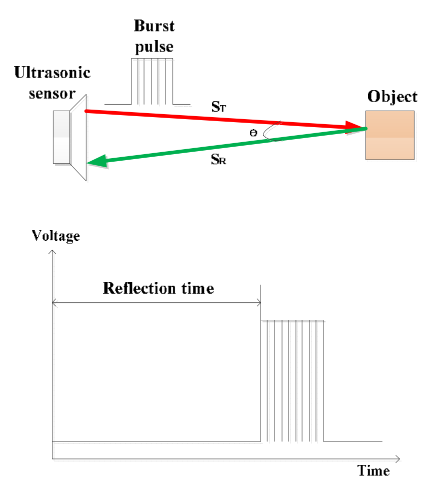

Fig. 4 Distance measurement process using ultrasonic sensor

B. Infrared measurement principle

This sensor is comprised of an LED and position sensitive detector (PSD). The PSD is a silicon component that operates on the principle of the photoelectric effect, in which light energy is turned into electrical energy. The emitter of the infrared sensor radiates the infrared light and when the beam strikes an object it is reflected back towards the sensor and into a focusing lens. The focusing lens directs the reflected beam onto the PSD.

C. Microcontroller working principle

Microcontroller unit is the core of the wireless obstacle detection system. PIC family microcontrollers were chosen as a core component in the transmitter and receiver part of the system. The microcontroller does not have an operating system and simply runs the program in its memory when it is turned on. PIC microcontroller is a small computer on a single integrated circuit which stores a set of instructions. It consists of a processor core, memory, and programmable input/output peripherals.

PIC is an important component in the proposed system which deals with a MicroC programming code which was installed in it. The microcontroller in transmitter part played an important role to read signals from sensors and calculate the distance value and convert the distance's analog value to digital value before sends the digitized data (distance) to the wireless transmitter module.

Whereas, in the receiver side, the microcontroller decodes and converts the distance value to TTL level logic data, then drive the specific alarm based on the value of the distance. Microcontroller displays the distance value and triggers the specific alarm (e.g. buzzer, vibrator or audio messages) based on the user requirements.

IV. RESULTS AND DISCUSSION

Several colors of the obstacle have been selected and tested accordingly. The colors of the surface of obstacle include white, black, red, yellow, blue and green. In this experiment, the measurement was conducted from 50cm to 150 cm.

A. Ultrasonic Sensor performance for different types of obstacle colors.

The voltage-distance characteristic obtained from US sensor at incident angle 90º is shown in Figure 6. The experimental results of the US sensor show that the output voltage of the sensor is proportional to the distance of the obstacle. Thus, linear curve characteristic is obtained from the measured data. The distance can be calculated from the output voltage as shown in equation (1) [16].

$$Measured\ distance\,(cm) = \left(\frac{output\ voltage}{9.766}\right) * 2.54 \quad (1)$$

A quick observation on the experimental results suggests that the output voltage for the US sensor does not depend on surface color and smoothness. In other word, the linear characteristic within its usable range is applied for all the color of obstacles.

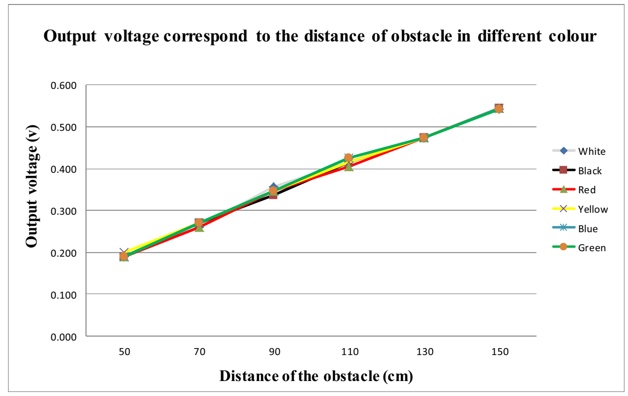

Fig. 6 Measurement result for the US sensor

Figure 7 shows the comparison between actual value and measured value for distance measurement using ultrasonic sensor. The calculated values have been taken by considering sound travels at about 343 meters per second. The percentage of accuracy for the US sensor varies from 96.38% to 97.76%, for all color of surface obstacle. The calculation of the accuracy is obtained from the equation (2) below [17].

Percentage of accuracy, A(%) = 100% - d% (2)

where d% = percentage difference

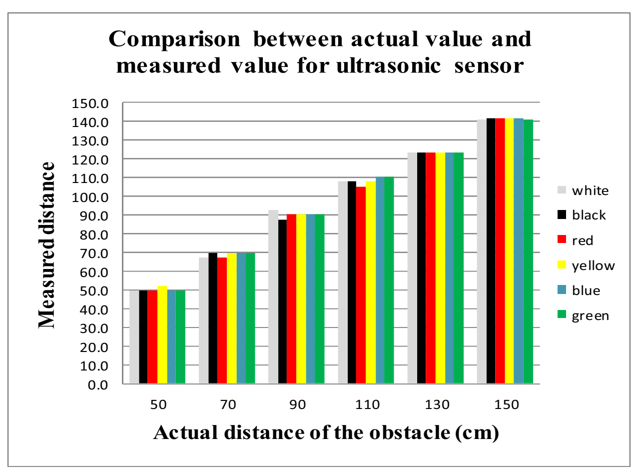

Fig.7 Comparison between actual value and measured value for ultrasonic sensor.

Based on these results, we observe that there is a small difference between the measured distance and actual distance. The percentage difference is increased especially at longer distances of the obstacle (e.g., 130cm and 150cm). The percentage of difference can be calculated using equation (3).

$$Percentage\ difference, d(\%) = \frac{|M_d - A_d|}{A_d} x\ 100\% \quad (3)$$

where,
$M_d = Measured\ distance$; $A_d = Actual\ distance$

Figure 8 shows the percentage difference for each surface color of obstacle using ultrasonic sensor.

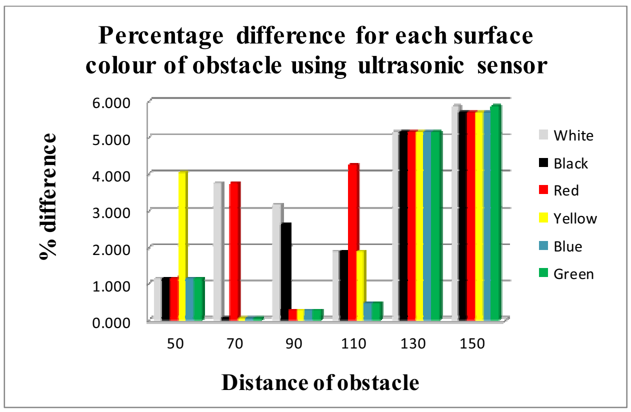

Fig. 8 Percentage of static measurement error for US sensor

B. Infrared Sensor measurement based on different types of surface color of an obstacle.

The type of material used as the obstacle is cupboard with different types of surface color. The voltage-distance characteristic obtained from infrared sensor is shown in Figure 9. The experimental result of the IR sensor shows nonlinear characteristic functions between sensor and the obstacle at the incident angle 90º.

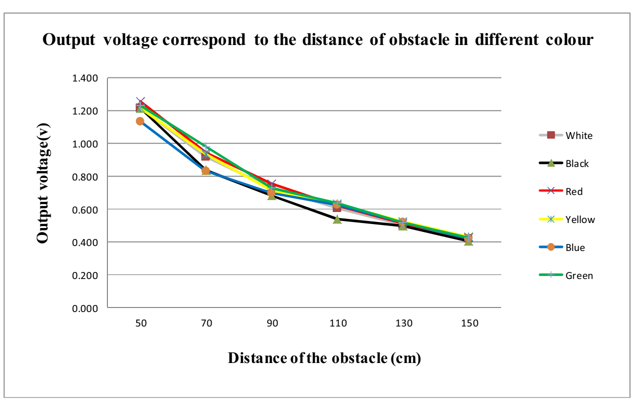

Fig. 9 Measurement result for the IR sensor

The amplitude of the output voltage across the IR sensor is decreased when the distance to an obstacle increased. Similar results are found when the incident angle is increased as shown in Figure 10. Environmental conditions could influence the measurement result such as sunlight, artificial lights, unless the external source is directly pointed towards the sensor [1].

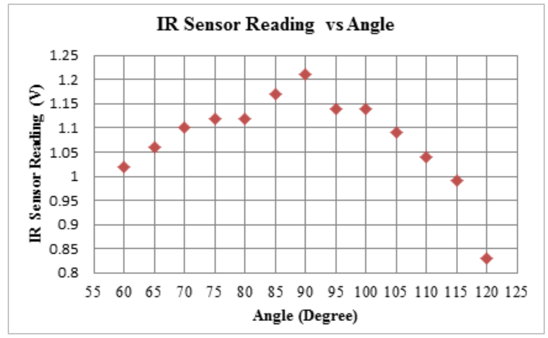

Fig. 10 Data collected from a flat surface 50 cm from IR sensor at different angles

The average output voltage value of the IR sensor in corresponding to the distance of the obstacle is obtained similarly with the technical datasheet produced by Solarbotics [14]. Because of the non-linearity of the output, data linearization must be applied to determine the distance measured. Data linearization could be done using nonlinear curve fitting method. Using the datasheet provided by Solarbotics, we used a fourth degree approximation method to get a close fitting formula to find the distance in cm from the voltage as shown in equation (4).

$$Measured\ distance(cm) = 16.2537x^4 - 129.893x^3 + 382.268x^2 - 512.611x + 306.439 \quad (4)$$

where, $x = distance\ value\ expressed\ in\ voltage$

Figure 11 shows the comparison between the actual distance and measured distance for the IR sensor.

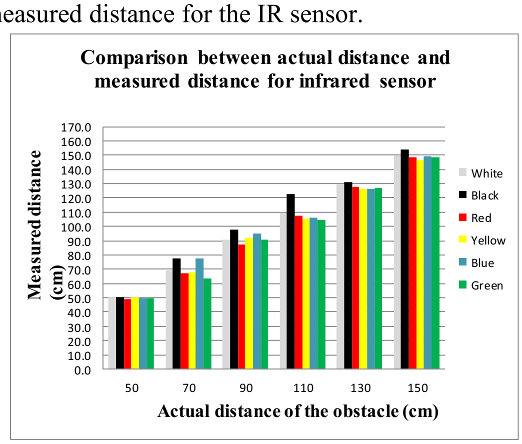

Fig. 11 Comparison between actual distance and measured distance for every color of the surface obstacle using infrared sensor

Using the same equation, it shows that the percentage accuracy of the IR sensor was varies from 94.7% to 99.5%. Therefore, we can conclude that for the incident angle of 0º, IR sensor has slightly better accuracy than US sensor. However, the percentage difference for measuring a distance using IR sensor is much higher especially for black and green colors of surface obstacle as shown in Figure 12.

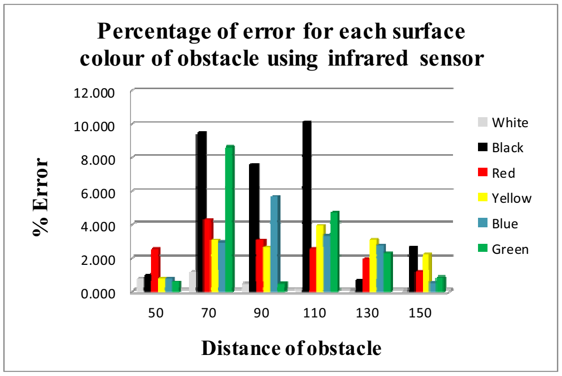

Fig. 12 Percentage difference for IR sensor

This is because of the dimensionless reflectivity coefficient; α_i for the black color is very low compared to others colors. Table 3 presents the dimensionless reflectivity coefficient for the others color.

TABLE 3 Experimental value of the dimensionless reflectivity coefficients, α_i for several colors of obstacle surface [18].

Material description	Relative IR reflectivity (α_i)
White cardboard	1.00
Yellow cardboard	0.99
Red cardboard	0.98
Light blue cardboard	0.97
Light green cardboard	0.94
Cyan cardboard	0.91
Light grey cardboard	0.90
Brown cardboard	0.78
Wooden panel	0.77
Red brick wall	0.61
Medium grey cardboard	0.59
Concrete wall	0.53
Black cardboard	0.12

C. Ultrasonic and Infrared Sensor performance based on difference types of surface material of an obstacle.

Measurements have been carried out for different type of obstacle materials; e.g., solid wood wall, plastic based product, mirror, plywood and concrete wall. Figure 13 shows the measurement results for both sensors at 0º angle and the obstacle, which is placed 50cm away from the sensors. These results are based on relatively large obstacles (5cm x 5cm), and the objective is to study the effect of color and materials of the obstacles.

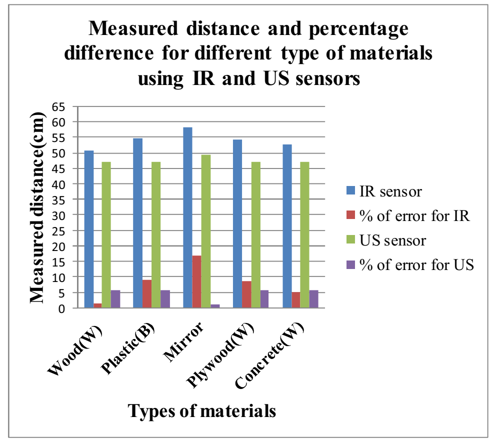

Fig. 13 Experimental results for different types of obstacle at 50cm from the sensors.

V. CONCLUSION AND RECOMMENDATIONS

This paper presented the use of ultrasonic and infrared sensors for distance measurement in the development of an obstacle detection system for elderly and people with vision impairment. Experimental results show that ultrasonic and infrared sensors have different characteristics in terms of output voltage measurements. It is clearly indicated that ultrasonic sensor gives a linear output characteristic whereas infrared sensor shows a nonlinear output characteristic. Both sensors are able to detect an obstacle at the distances within their usable range with percentage of accuracy between 95% and 99%. The experimental result indicates that the US and IR sensors are able to provide reliable distance measurements even with different colors and materials of obstacles. It has been shown that IR sensor has slightly higher resolution than that of the US sensor, especially for small distance measurement within their usable ranges. Future work, the system should determine the sensor location on the shoe, and the sensors only detect the obstacle when the foot fully touching to the ground.

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