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Research paper

Design and implementation of ultrasonic radar system for distance measurements using Arduino

Haraa Raheem Hatem [1]*, Ali I. Abdalla [2], Zainab Najeeb Abdulhameed Al-Rawi [3]

[1,2] *College of Engineering, University of Diyala, Iraq*
[3] *College of Engineering, University of Anbar, Iraq*
**Corresponding author E-mail: Haraa_altaie1980@yahoo.com*

Abstract

Radar is an electronic device which utilizes electromagnetic waves to determine the altitude, range, direction, or speed of both moving and immovable objects. In contrast, ultrasonic waves are used instead of electromagnetic waves in ultrasonic radar. The low power consumption, low cost and ease of implementation are considered the main features of the ultrasonic radar to be devoted in several applications such as security purposes, object detection and avoidance systems in robotics. This work presents a design and implementation of ultrasonic radar for distance measurements. The design consists of an ultrasonic sensor, an Arduino board as a controller, a servo motor and a java applica-tion. The detection range of the proposed system is tested up to 500 cm with the angle of rotation from (0 to +180) and (180 to 0) degrees for different types of obstacles or objects (sponge, wood an aluminum). The design is built using open source hardware (Arduino Uno 328) which is coded via Micro C environment as a software entity. The effectiveness of the proposed design is measured using a statistical analysis of the distance error between the radar and the obstacles. The results obtained for all types of obstacles are tabled and graphed to prove that a very small error can be achieved using the proposed design.

Keywords: *Arduino Uno 328; Ultrasonic Sensor; Servomotor; Java Application.*

1. Introduction

Radar is an information provider of an objects that cannot reached directly. This information is related to distance, depth, direction, speed, etc. The principle of operation of radars is unique; sending and receiving waves through a specific medium that allow such waves to pass through at a low level of attenuation [1]. Ultrasonic wave which placed beyond the audible frequency range (20Hz to 20,000Hz) is the key point of operation of ultrasonic radar. Each ultrasonic radar must include ultrasonic detector (sensor) that operates as a transformer of ultrasonic waves to electrical form and vice versa [2]. Ultrasonic detectors have several positive features such as, cheapness, higher sensing range, better robustness during environmental changes rather than other types. Furthermore, the ability of expanding the sensing range by controlling the signal attenuation and the circuit sensitivity [3].

Literately, a distance measurement by using ultrasonic waves was implemented experimentally by (A. K. Shrivastava, et al., 2010). A P89C51RD2 chip was used as a microcontroller beside the ultrasonic sensor. The experimental results show that the error is decreased by increasing the distance between the object and the sensor [4]. However, the distance of the measurements does not exceed 50 cm. (Bari Harshal Suni, 2014) presented one of the applications of ultrasonic sensors. The design includes an At89c51microcontroller and represents a security system for homes to detect human body movement and produce a required alarming message. The design was implemented and tested successfully without error [5]. However, the system must include a GSM modem that add complexity to the design. A combination of three sensors with a PIC16F877A microcontroller were implemented by (Huthaifa Ahmad Al Issa, et al., 2016) to produce a smart device for several applications. One of these sensors is an ultrasonic sensor which functioned to measure a distance to an object [6]. Nevertheless, the results related to distance measurements does not mention the distance between the object and the device rather than the error of the measurements. (Shengbo Eben, Li et al., 2017) presented a design of an array of ultrasonic detectors with Arduino board for sensing moveable objects. Both the effective area of the object and its shape were taken in the account for precise measurement [3]. However, the angle of rotation to the center line was from -60^o to +60^o. This work aims to design and implements an ultrasonic system for distance measurements using Arduino board for a distance up to 5m with a (0 to 180) and (180 to 0) degrees coverage range.

2. Hardware and software components

A brief description of the components that used in the implementation of the design is covered in this section. It includes the hardware components (Arduino Uno board, ultrasonic sensor, and servo motor) and also the processing software.

2.1. Arduino UNO

Arduino is a physical computing platform that released under open-source license and based on a simple microcontroller board (Figure 1). Integrated Development Environment (IDE) is devoted for coding the device. In most applications, the Arduino board is used as a controller. Initially, the device requires a direct connection to a computer at the first setting steps. However, it can function efficiently without this connection according to the application requirements [7].

Fig. 1: Arduino Uno Board.

2.2. Ultrasonic sensor HC-SR04

Ultrasonic sensor is the corner stone of any ultrasonic device. The principle of operation of a radar or sonar can be used to understand the operation of ultrasonic sensor due to the similarity of operation. In other words, by evaluating the time required for sending and receiving the ultrasonic wave, several information related to the object or obstacle that causes the reflection of the wave can be measured such as the distance to the sensor, size, figure, etc. [6]. Tow parameters usually affect the speed (v) of ultrasonic wave in a specific medium; the medium nature and its temperature; as explained in Equation 1.

$$v = 340 + 0.6(t - 15) \quad m/s \tag{1}$$

Where:
t, is the temperature of the medium in °C.
340 m/s, is the speed of the sound in the air which can be used instead of ultrasonic wave speed due to the short distance of operation of ultrasonic Sensor in the design (less than 5m) [4].
The parameters of HC-SR04 ultrasonic sensor (Figure 2) that used in the design is summarized in Table 1.

Fig. 2: The Ultrasonic Sensor.

Table 1: Specifications of Ultrasonic Sensor HC-SR04

Parameters	Ultrasonic sensor HC-SR04
Working voltage	5V (DC)
Working current	Max 15 mA
Working frequency	40 KHz
Sentry distance	2cm-500cm
Input trigger signal	10µs TTL impulse
Echo signal	Output TTL PWL signal

2.3. Servo motor

A servo system refers to a feedback control loop system for controlling one or several parameters in such system. In case of servomotor (Figure3) that is considered as a linear rotary actuator, the parameters to be controlled are acceleration, speed and/or position. The servomotor system for position or distance measurements usually includes a special motor, a sensor for error signal requirements and a controller. CNC machines, robots and automation are a clearly applications of servomotors [7, 8]. In this work, a servomotor (which provide ±90 degrees rotations) is used beside both the Arduino board and the ultrasonic sensor HC-SR04 for position determination.

Fig. 3: Servomotor.

2.4. Processing software

Processing (Figure 4) is an Integrated Development Environment (IDE) designed for several purposes such as electronic arts and visualizing the fundamentals of programing. Arduino as an IDE builds in Java language, but uses a simplified syntax and graphics programming model [9-10].

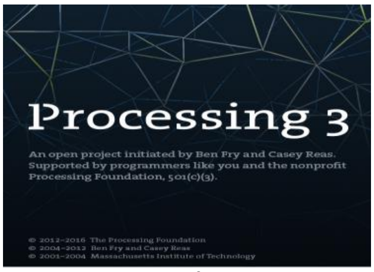

Fig. 4: Processing Software (Version3.0).

3. Experimental setup

The proposed design consists of ultrasonic sensor (HC -SR04) that coupled with the servomotor. The combination is controlled by Arduino board to identify the distance between an object and the sensor. In this work, the materials: wood, sponge and Aluminum are chosen for the objects to validate the design operation.
The measurements have been recorded over the distance of (50-500) cm at different angles (from 0 to 180 degrees). The controller is interfaced with a computer to display the ranging screen of the radar (Figure 8). The implementation of the system is shown in Figure 5 and the experimental setup is shown in Figure 6 and Figure7 during operation and setup respectively. The performance of the designed system for a specified obstacle is measured by finding the percentage error according to Equation 2.

$$Error = \frac{real\ distance - measured\ distance}{rael\ distance} * 100\ \% \tag{2}$$

Where the parameters (real distance) and (measured distance) represent the distance in (cm) between the object and the system measured manually and by the system respectively. The ranging screen of the setup to be appeared for a specific measure is shown in Figure 8. This screen provides information related to the angle and distance of an object. For instance, at angle 34 degrees, there is an object placed at 409 cm from the sensor with an error according to Equation 2. Several reasons could lead to this error such as the change of temperature, wind speed and random noises; in fact, these reasons affect the ultrasound wave. Equation 3 is applied to calculate the distance at t=15°C.

$$Distance(cm) = \frac{trarvel\ time * 10^{-6} * 34000}{2} \tag{3}$$

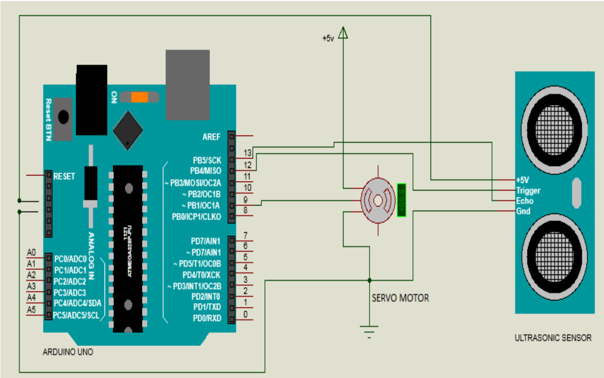

Fig. 5: Electronic Circuit of Ultrasonic Radar.

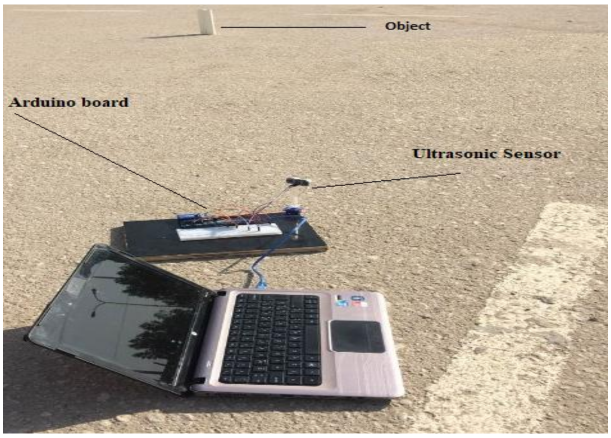

Fig. 6: Hardware Setup (During Operation).

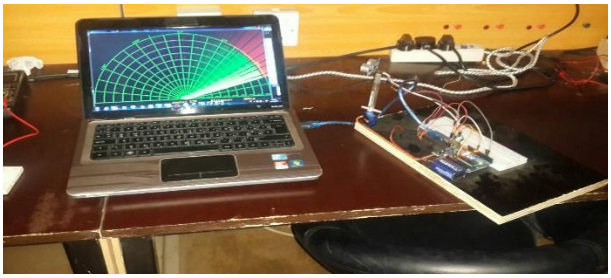

Fig. 7: Hardware Setup (During Setup).

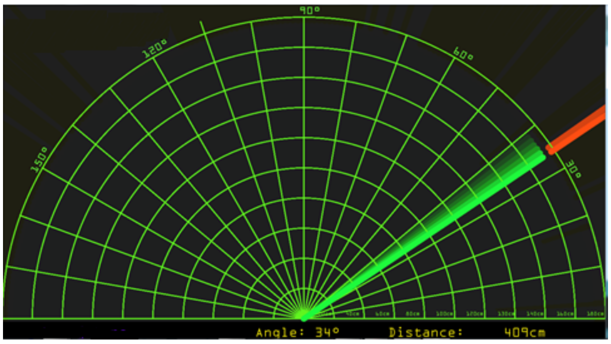

Fig. 8: Ranging Screen.

4. Experimental results and discussions

The validation of the design has been tested experimentally in the campus of College of Engineering/ University of Diyala/ Iraq. Three types of materials (wood, sponge and Aluminum) are considered as an obstacles; as stated in previous section; due to their popularity in many applications. The obtained results for each material are graphed and tabled to clearly focus on the difference between the real and measured distances to conclude the error of the measurement.

4.1. Wood obstacle

Figure 9 and Table 2 summarize the results of distance measurements in case of wood obstacle. It can be noticed that the maximum percentage error between the actual distance and measured distance is about 2% and most readings are less than 1%.

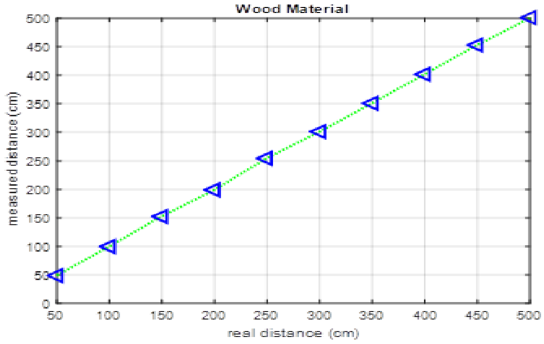

Fig. 9: Relation between Measurement and Actual Distance for Wood Obstacle.

Table 2: Experimental Results (Wood Obstacle)

Real distance (cm)	Measured distance (cm)	Error % (wood)
50	49	2%
100	100	0.0%
150	153	2%
200	199	0.5%
250	255	2%
300	301	0.33%
350	351	0.2%
400	402	0.5%
450	453	0.6%
500	502	0.4%

4.2. Sponge obstacle

In this case; as shown in Figure 10 and Table 3; the percentage error in most cases is larger than the opposite values of wood obstacles and the maximum value of the error is about 7%.

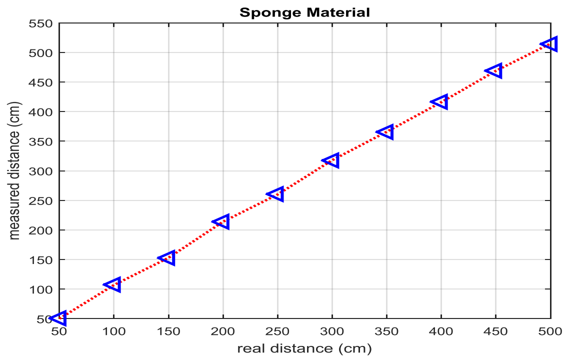

Fig. 10: Relation between Measurement and Actual Distance for Sponge Obstacle.

Table 3: Experimental Results (Sponge Obstacle)

Real distance (cm)	Measured distance (cm)	Error % (wood)
50	50	0.0%
100	107	7%
150	153	2%
200	214	7%
250	260	4%
300	318	6%
350	366	4%
400	416	4%
450	469	4.2%
500	515	3%

4.3. Aluminum obstacle

In case of Aluminum obstacle; as explained in Figure 11 and Table 4; the percentage error of most measurements is larger than the measurements in case of wood obstacle and less than the measurements of sponge obstacle.

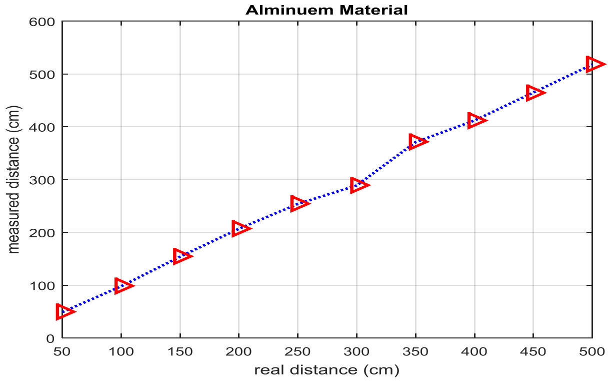

Fig. 11: Relation between Measurement and Actual Distance for Aluminum Obstacle.

Table 4: Experimental Results (Aluminum Obstacle)

Real distance (cm)	Measured distance (cm)	Error % (wood)
50	49	2%
100	98	2%
150	154	2.6%
200	207	3.5%
250	254	1.6%
300	289	3.6%
350	371	6%
400	412	3%
450	465	3.3%
500	518	3.6%

According to the results of the percentage error for the measured distance using the proposed design. It can conclude that the design is working properly at an acceptable error.

5. Conclusion

In this work, an ultrasonic radar system was designed and implemented experimentally for distance measurements purposes to be used in various applications. An Arduino Uno device was used as a controller in the design beside other requirements such as servomotor, ultrasonic sensor and computer for distance calculation of objects or obstacles placed at different angles (from 0 to 180 degrees) within the range up to 5 meters. Three types of materials (wood, sponge and aluminum) were used in the design as obstacles. The error between the actual distance and measured distance was used statistically to validate the design. The results show that the percentage distance error recorded for wood, sponge and aluminum obstacles do not exceed 2%, 7% and 6% respectively which can be accepted in many applications.

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