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Implementation of ranging system using ultrasonic sensor and microcontroller unit for aviation industries

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Abstract

In the aviation industry, radio detection and ranging is employed to evaluate the height, distance, bearing, size, trajectory or velocity of both dynamic and static objects. Ultrasonic waves can also be used instead of electromagnetic waves in ultrasonic sensor. This research paper presents the real time implementation of a less-expensive ultrasonic detection and ranging system built based on Arduino Uno 328 microcontroller. It utilizes ultrasonic sensors attached to a servo motor which rotates from 0^0 to 360^0 to detect an object in range within 400cm which passes the data to an Arduino microcontroller, this then gives visual representation on the software called Processing-3.5.4 software (Processing development Environment) java language. The Processing displays on an LED (Light Emitting Diode) screen graphical information such as bearing, size, range and position of the object depends on the proximity of the object to the ranging system. Result obtained shows a maximum a good maximum error of 7 % for the test object considered. Hence, this system can be deployed in the field.

Keywords: Aviation; Ranging; Ultrasonic; Microcontroller

1. Introduction

Ranging detection system is used in Aviation Industries as well as Aerospace Industries as a means of monitoring air traffic, preventing mid-air collision, automatic guided landing of Manned and Unmanned Aerial vehicles and well as means of detecting Unidentified Flying Objects (UFOs). Plane crashes and mid- air collisions can be as a result of factors such as ; pilot fatigue, bad weather, delay in communication due to static interference , carelessness, equipment malfunction of onboard guidance system of the aircraft. In the aviation industry, the air traffic control towers need to monitor round the clock the position, range, altitude, size, identity of all inbound and outbound aircrafts and UFOs to avoid air collision and plane crashes. Ground and Airborne based radars are efficient and accurate micro variation monitoring technology, which has played an important role in monitoring of obstacles and cluster for identification and detection of target [1-3].

There are few related works that examine range determination. In 2014, Bari Harshal Suni presented one of the applications of ultrasonic sensors. The design includes an AT89C51 microcontroller and represents a security system for homes to detect human body movement and produce a required alarming message [4]. The design was implemented and tested successfully without error.More so, the tracking is performed in the range Doppler domain where the moving objects may appear but of the clutter region, improving their detectability [5].

Installation of cost-efficient ultrasonic radar system in the aviation industry will significantly reduce and prevent air collisions, plane crashes due to bad weather or other uncontrollable natural phenomenon, moreover, light detection

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and ranging (LiDAR) data, have been used for object detection with high success rate [6]. It alerts the pilot of any object in proximity to the aircraft and can even land the aircraft safely without human aid. Currently, technological advances in radar system is efficiently being used in Radio Astronomy, Submarine and ship navigation, Landing Spacecraft/probes on planet Mars, accurate meteorological information, and ground penetrating radar for geological survey, missile guidance system and missile interception system [7]. Advance and portable radar systems such as the Radar gun is used by low enforcement agencies in developed countries to monitor the speed of vehicles such as Cars [8]. Furthermore, camera based approach have been proposed as an alternative which have similar performance with radar based approached and apparent advantage in terms of ward wave [9].

In line with this related works, range detection via ultrasonic waves was implemented experimentally for this research. A P89C51RD2 chip was used as a microcontroller besides the ultrasonic sensor. he scope of this study is within aviation safety and navigation systems. A low-cost ultrasonic radar detection system with a programmable microcontroller was designed and implemented. The system was fabricated on a single Printed Circuit Board (PCB) with an ultrasonic sensor controlled by an Arduino microcontroller with a servo motor to rotate the ultrasonic sensor from 0^0 to 360^0 and vice versa, a Processing-3.5.4 software (Processing development Environment) to display the bearing and range of an object in close proximity (i.e. within the radar range) on an LED screen, which also provide superior long range, real time, high resolution imaging and wide area search capability [10].

2. Review of the system hardware and software

This section provides an overview of the components used to implement the design for this work. The hardware (Arduino Uno board, ultrasonic sensor, and servo motor) as well as the processing software are included.

Arduino Uno Board: Arduino (Fig. 1) is a hardware and software firm, project, and user community that creates open-source hardware, software, and microcontroller-based kits for making digital devices and interactive things that can sense and control physical items. Microcontroller board designs are used in this project. The board has digital and analog input/output (I/O) pins that can be used to interact with various expansion boards (also known as shields) and other circuits. For loading applications from personal computers, the boards provide serial connection connectors, including USB on the Uno model.

The Arduino project provides an integrated development environment (IDE) for programming the microcontrollers, which makes writing code and uploading it to the board simple. Windows, Mac OS X, and Linux are all supported. The environment is made up of Processing and other open-source software and developed in any high-level language. Any Arduino board is compatible with this software [11, 12]. In most cases, it is certain that there will be some measurements not included at certain azimuth times [5]. This could be due to the low backscatter received from the moving target or when the target is not illuminated by the antenna beam.

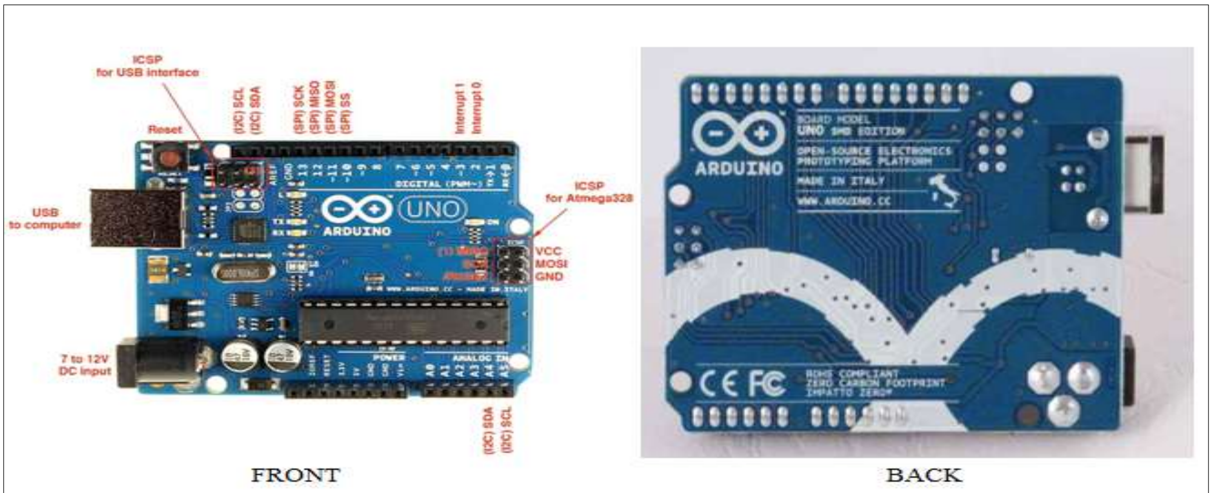

Figure 1 Arduino Uno Board

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. Hence, by evaluating the time required for transmitting and receiving the ultrasonic wave, several information such as the range to the sensor, size, bearing etc related to the object or obstacle that causes the reflection of the wave (Fig.2) can be measured [13].

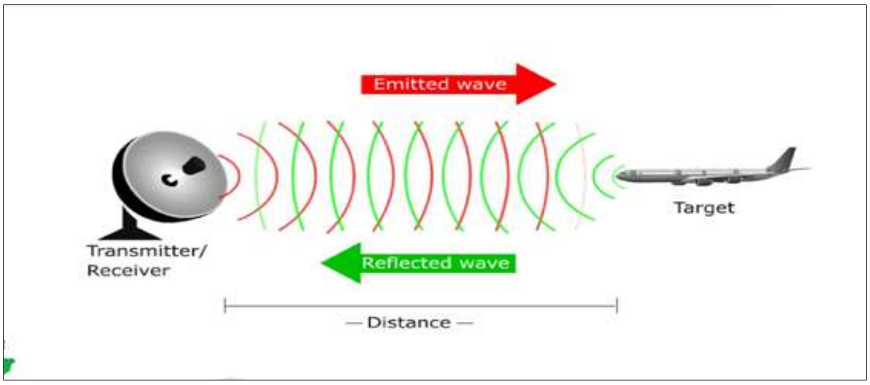

Figure 2 Transmitting and Receiving Reflected Echo/wave from Signal

The speed (v) of an ultrasonic wave in a certain medium is affected by two key parameters: temperature and medium nature. This is seen in Equation 1.

$$v = 340+0.6t-9\ m/s \quad (1)$$

However, because of the limited distance of operation of the ultrasonic sensor in the design (4m), 340 m/s is the speed of sound in dry air that can be utilized instead of ultrasonic wave speed. A pictorial view is given in Fig. 3.

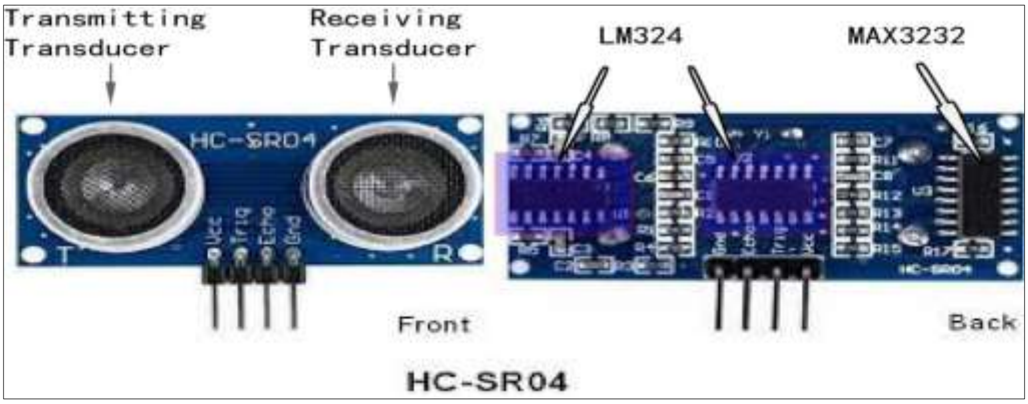

Figure 3 An HC-SR04 Ultrasonic Sensor

The technical parameters and pin configurations/assignments of HC-SR04 ultrasonic sensor (Fig.3) that was used in the design is summarized in Tables 1 and 2.

Table 1 Operating parameters of the Ultrasonic Sensor HC-SR04

Electrical Parameters	HC-SR04 Ultrasonic Module
Operating Voltage	5V DC
Operating Current	15Ma
Operating Frequency	40KHz
Max. Range	400cm
Nearest Range	50cm
Measuring Angle(Bearing)	15^0

Input Trigger Angle	10µs min.TTL Pulse
Output Echo(Reflected) Signal	TTL level signal is proportional to distance
Board Dimensions	1.13/16' X 13/16' X 5/8'
Board Connections	4X0.1 Pitch Right Angle Header Pins

Table 2 Pin Configuration of the Ultrasonic Sensor HC-SR04

Pin	Pin Symbol Pin	Function Description
1	VCC	5V power supply
2	Trig	Trigger Input pin
3	Echo	Receiver output pin
4	GND	Power Ground

2.1. Servo motor

This is a rotary actuator or linear actuator that can control angular linear position, velocity, and acceleration with precision. It's little and light, yet it packs a punch. The servo has a maximum rotational angle of 360^0 (180^0 in each direction) and functions similarly to regular servos but in a smaller size. A specific motor, a sensor for error signal requirements, and a controller are commonly included in a servomotor system (Fig.4) used for position or distance measurements. Servomotors are used in cutting machines, printing machines, automation, and robotics, to name a few. For this project, a servomotor (with 180^0 revolutions) was used in conjunction with an Arduino board and the HC-SR04 ultrasonic sensor to determine position.The architecture is presented, with a description of the platform motion compensation system and its performance [4, 8].

Figure 4 Servomotor

2.4 Processing software Version 4.0: Depicted in Fig.5, it is an open source computer programming language and integrated development environment (IDE) built for the electronic arts, new media art, and visual design communities with the purpose of teaching the fundamentals of computer programming in a visual context. In addition, synthetic aperture is formed by means of effective rotation of the target [14].

Figure 5 Processing Software(Version 4.0)

2.5 Arduino Software: This application software was used in programming the Arduino microcontroller [11]. It is an open source platform. It was downloaded from the Arduino software website (Fig. 6).

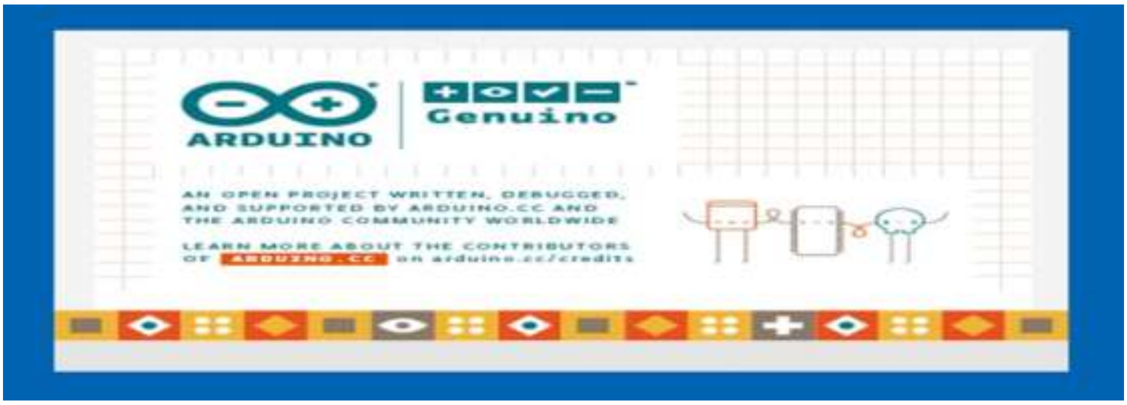

Figure 6 Arduino Software and Program

3. Model Experimental setup

Two ultrasonic sensors (HC -SR04) are linked with a servomotor in the prototype model. To determine the distance between an object and the sensor, the entire device is controlled by an Arduino Uno board. To validate the design operation, a piece of foam, wood, and aluminum were used for the objects in this project. The measurements were taken at different angles ranging from 0^0 to 360^0 from a distance of 50cm to 400cm. The controller connects to a computer via USB to display the radar's range screen. Fig.7 depicts the system's implementation, whereas Fig.8 and Fig.9 depict the experimental setup during operation and setup, respectively. The designed system's performance against a specific impediment is measured in the equation 2. More so, it enables very high detectable in real-time processing, combining with the latest track association technology, the method can yield better performance [15].

$$\%Error = \frac{Actual\ Distance\ - Measured\ Distance}{Actual\ Distance} \times 100\% \qquad (2)$$

Parameters such as actual distance and measured distance are represented in centimetres (cm). As a way of verification, measurements were taken both manually and by the system. Fig. 8 shows the setup's range screen for a given measurement. This screen displays information about an object's angle (bearing) and distance (range). According to Eqn. 2, an object placed at 77 cm from the sensor at an angle of 340 has an error. Several factors, including changes in temperature, wind speed, and random noises, can cause such an error; in fact, these factors have an impact on the ultrasonic wave. When the surrounding temperature is, Eqn. 3 is used to calculate the distance. Also, azimuth and accuracies are discussed, introducing a statistical radar studies based on the processed data [4].

$$Distance\ in\ (cm) = \frac{Travel\ time\ \times\ 10^{-6} + 3400}{2} \qquad (3)$$

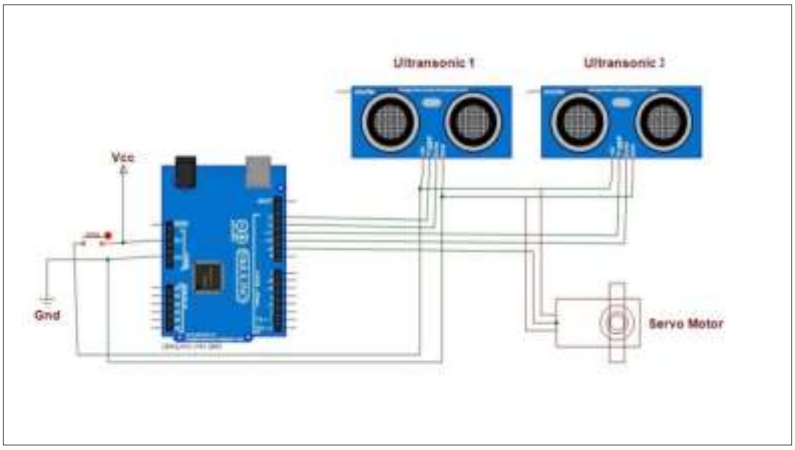

Figure 7 Electronic Circuit of Ultrasonic the Radar

Figure 8 Hardware Setup(During Operation)

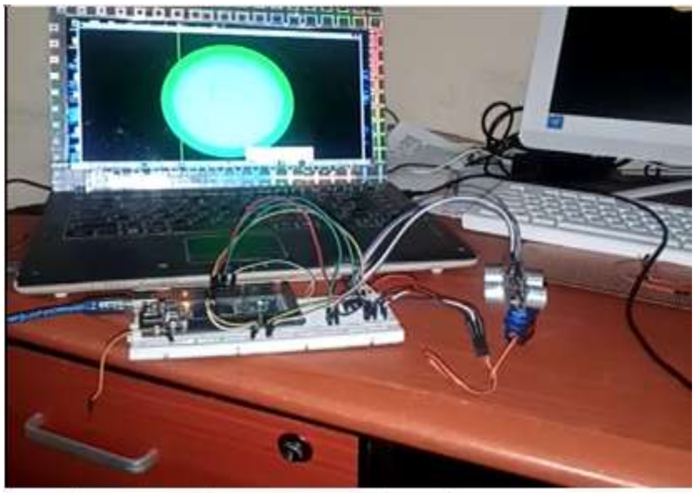

Figure 9 Hardware Setup (During Setup)

4. Results and discussion

The construction was successfully implemented and evaluated experimentally in an electronics laboratory, Department of Electrical and Electronic Engineering, Nigeria Defence Academy, Kaduna, Afaka Campus. The following materials; Foam, wood and Aluminium were used as obstacles due to their wide range of applications. The experiment's results were summarized and graphically explained for each material, with the major focus on the difference between the actual and measured distances in order to compute the percentage error measurement using a near field measurement chamber, measured transmit pattern and effective isotropic radiated pattern of obstacle detection [5, 8]. This is similar to the design using distant mounted Receiver antennas which allows a dual-channel operation for different polarization settings, and imperatively provides a high isolation between Transmitter and Receiver paths [16]. The ranging section is depicted in Fig. 10. The results obtained based on materials are presented in the upcoming section

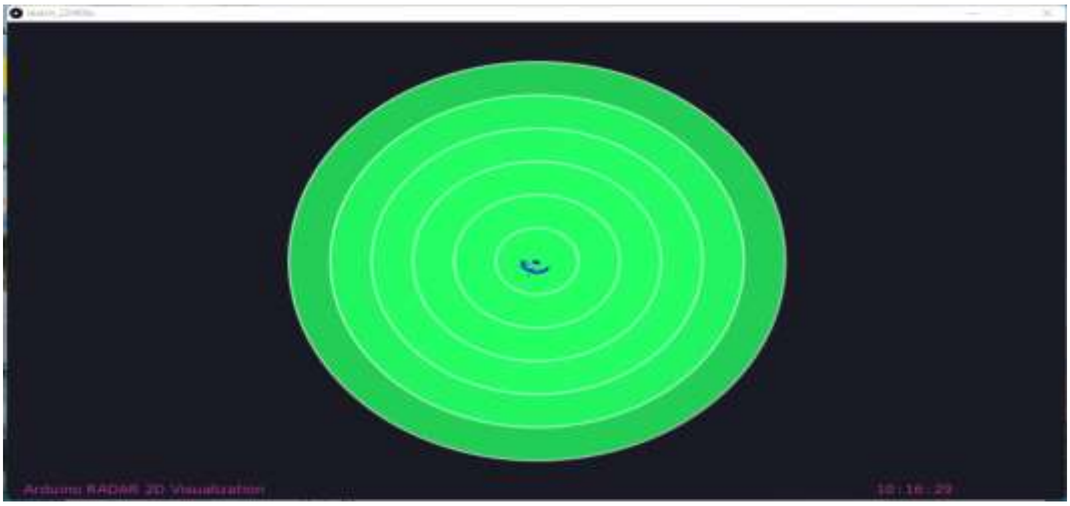

Figure 10 Ranging Screen Showing Objects

4.1. Foam Obstacle

The findings of distance measurements in the event of a foam obstacle are summarized in Table 3. The largest percentage error between the real and measured distances is approximately 6.80 percent, while the majority of readings are at low percentage. More so, phase angle data only method gives better detection and computation time, the current aviation industry still using radar system in monitoring and controlling the system [17].

Table 3 Experimental Result (foam)

Real/Actual Distance(cm)	Measured Distance(cm)	Percentage Error(foam)
50	50	0.00%
100	106	6.00%
150	154	2.60%
200	212	6.00%
250	267	6.80%
300	316	5.33%
350	368	5.14%
400	418	4.50%

Foam obstacle is shown in Table 3 to represent materials that absorb ultrasonic waves by dampening their intensity or totally stopping them from reflecting, these are mostly found in stealth aircrafts and drones.

4.2. Aluminium Obstacle

In case of Aluminium obstacle; as explained in Table 4, the percentage error of most measurements is larger than the measurements in case of wood obstacle and less than the measurements of foam obstacle.

Table 4 Experimental Result (Aluminium)

Real/Actual Distance(cm)	Measured Distance(cm)	Percentage Error(Aluminium)
50	49	2.00%
100	97	3.00%
150	153	2.00%
200	208	4.00%
250	256	2.40%
300	288	4.00%
350	373	6.57%
400	411	2.75%

Aluminium obstacle as depicted in Table 4 represents materials used in aircraft fuselage. It is an excellent reflector of ultrasonic waves with minimum sound absorption compared to other obstacles used in this experiment. Most aircraft are made up aluminium or aluminium alloys. Hence, the distance measured using ultrasonic range detection system when compared to actual distance of an object from the sensor array is almost the same and has minimal error. Compared to other obstacles used, this has the least errors in measurement. Once again, vertical bar charts depicts distances as detected by the ultrasonic transducers, while the horizontal axis represents the actual distances from an object to the sensor array of the ultrasonic range detection system.

4.3. Wood Obstacle

In case of wood obstacle as shown in Table 5, the percentage error of most measurements are larger than the measurements in case of wood obstacle and less than the measurements of foam obstacle.

Table 5 Experimental Result (Wood)

Real/Actual Distance(cm)	Measured Distance(cm)	Percentage Error(Wood)
50	49	2%
100	100	0.0%
150	153	2%
200	198	1%
250	253	1.2%
300	299	0.3%
350	353	0.86%
400	401	0.25%

Polished wood reflects sound better than unpolished wood, the results of Table 5 are used to represent a special fiberglass materials used in drone construction and has similar properties with polished. Drones are not easily detected by long range radar system due to their size and materials used in constructing them, ultrasonic range detection system is an excellent option in identifying drones especially at close proximity.

Ultrasonic radar system needs a medium to travel through, which makes it an unlikely choice for vacuum such as outer space. The speed of the signal depends on the environment in which the radar system is operating since sound waves travel at different speeds depending on air temperature, pressure and gas composition of the medium. Because any of these variables can cause measurement error, ultrasonic radar systems are better suited for level measurements in processes with little to no changing conditions.

The frequencies of ultrasonic transmissions range from 30 to 240 kHz. Unlike traditional radar, frequency is more of a function of measuring range, with low frequencies being used to measure longer distances and high frequencies being used to measure shorter distances. Although certain ultrasonic sensors can focus most of their signals into a tiny 40 or 50 beam angle, ultrasonic sensors are more prone to receive undesired echo due to the form of acoustic waves.

In the instance of the foam obstacle, the findings of distance vs. sensitivity in measurements are summarized in Table 3. The greatest percentage error between the real and measured distances is not more than 2.0%, and the majority of readings are less than 1.00%. The findings of distance measurements with wood as an impediment are summarized in Table 5. The largest percentage discrepancy between the actual and measured distances is roughly 2.0%, with most readings falling between 0.0 and 1.2 percent. As shown in Table 4, when an aluminum obstacle is used, the percentage error of most estimation is higher than when a wood obstacle is used. Limitation of this project is height of objects cannot be determined, 3D mapping of object is not possible and the range depends upon the characteristics of the sensor.

5. Conclusion

An ultrasonic radar system was conceived and built experimentally in this study for distance measurement applications in traffic control towers in the aviation industry. The design included an Arduino Uno device as a microcontroller, as well as a servomotor, ultrasonic sensor, and computer for calculating distances between objects or barriers positioned at various bearings (0^0 to 36^0) within a range of up to 400cm. As barriers, three different types of materials (wood, foam, and aluminum) were used. The differences in real and measured distances were statistically used to validate the design. The percentage distance error reported for wood, foam, and aluminum barriers does not exceed 2.00 percent, 6.80 percent, and 6.57 percent, respectively, according to the results.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

Statement of informed consent

Informed consent was obtained from all individual participants included in the study.

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