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RODDMS-IoT: A Radar Based Real-Time Moving Object Detection and Distance Measurement System Using IoT for Enhanced Safety

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The main users of RADAR (Radio Detection and Ranging) in its early development for security and monitoring purposes were the navy, the military, the aviation services, as well as the space organizations. Nowadays, the demand of radar is expanding. But it takes a while to detect, has a limited detection area, lacks target specificity due to its wide range, oversensitive, costly, etc. A cheaper, easy and effective alternate solution is to use ultrasonic sensor which use sound waves for detection and ranging. Therefore, this study offers a technique for using the Ultrasonic Sensor

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(HC-SR04) as RADAR. For the purpose of rotation and movement, the Servo Motor (SG90) is connected to the Ultrasonic Sensor (HCRS04). The SIM808 IoT integrated GPS-GSM module is also utilized to send out SMS notifications for object identification. These components are connected to an Arduino Uno and a Raspberry Pi3 to detect and notify the object. Additionally, the goal of this work is to capturing the distance, direction, and radar pulse duration and object shape simultaneously. An algorithm was used to determine the object's velocity, or its speed toward or away from the radar, in order to acquire the precision. By comparing the actual values with the data acquired by the radar, the accuracy of the measurement of both angle and distance is ensured. There are both metal and non-metal objects used in this study. This work's novelty lies in its ability to accurately detect real-time moving objects and measurement the distance of the objects. Besides proper distance and velocity, a large set of data was taken to find the accuracy of the radar for objects of different shapes. The results show the object detected with its distance and angle in a java based Graphical User Interface (GUI), different ranges of object in cm at which it is detected and the detection notification sent to the admin via SMS.

Keywords: RADAR; ultrasonic sensor; SIM808; SMS; GUI; object detection; distance measurement, IoT.

1. INTRODUCTION

“It was challenging to manually detect, identify, and track objects during the World Wars. It was difficult, even for a human, to forecast the weather. As the water bodies are huge and what lies beyond them isn’t visible, it was difficult for humans to travel or explore. Therefore, RADAR was invented to solve these problems. It is employed in the military to guide missiles or to detect and identify targets or enemies. In the aviation industry, it can manage air traffic by locating aircraft and guiding them to land or take off safely, even in inclement weather. In remote sensing, radar can be used to predict weather to take the necessary steps in case of natural disasters, to track satellites, to observe planetary positions in space, to guide ships in the water bodies or to discover objects lying beneath them. Radar is also used by police officials to detect speed of the vehicles, to detect obstacles and so on. The RADAR consists of a transmitter which produces an electromagnetic signal which is radiated into space by an antenna. This signal is reflected in multiple directions when it strikes any object. The radar antenna picks up this reflected or echo signal and sends it to the receiver, where it is processed to determine the geographical statistics of the object. The time it takes for a signal to go from radar to a target and back is used to calculate the range. The target’s location is measured in angle, from the direction of maximum amplitude echo signal, the antenna points to the measure range and location of moving objects, Doppler Effect is used” (Sairam et al., 2018; Soni et al., 2017).

Working procedure of RADAR System is shown in Fig. 1. “RADAR can be used in weather condition to detect object, as it uses electromagnetic wave, it doesn’t need a medium to travel through, it has long range, flexible, etc. But it is costly, not east to setup or handle, too close objects deviate the receiver, not target specific because of its wide range. But a better solution in means of handling and affording is available. Ultrasonic sensors measure the distance by using ultrasonic sound waves which are above the human audible range 20kHz. The sensor emits an ultrasonic wave and receives the wave reflected back from the target (Huque et al., 2023; Huque et al., 2023). Ultrasonic Sensors measure the distance to the target by measuring the time between the emission and reception. The advantages of ultrasonic sensors are that they are cheap, easy to setup and handle, can be interfaced with any IoT module, high frequency, sensitivity, penetrating power, great accuracy, easily sense the nature, shape, orientation of the object, they are independent of light, smoke, color, dust, material, etc (Ali et al., 2022; Hossain et al., 2024). In recent years, the Internet of Things (IoT) technology has gained significant attention due to its potential in various applications” (Li et al., 2012; Yadav et al., 2018). Most of the authors (Kumar et al., 2017; Sunitha, 2017; Goswami et al., 2021; Rahman & Sadi, 2021; Arıbaş & Dağlarlı, 2017) used IoT to their works. Therefore, they are used for liquid level control, car parking system, distance measurement and almost all the applications of RADAR.

“Therefore, in the proposed work, ultrasonic sensor (HC-SR04) is used which is made to act as RADAR. The ultrasonic sensor measures an object's distance using sonar. A high-frequency sound signal is sent by the transmitter (trig pin), when the signal finds an object, it is reflected and the transmitter (echo pin) receives it. Servo motor SG90 is used for movement/rotation similar to RADAR. SIM808 can be used to notify the object detection via SMS/message with its location" (Bystrov et al., 2014; Wobschall et al., 2005). As one can see that with these cheap, lightweight, easy to setup and handle modules, the RADAR can be replaced and even then, all the application can be handled. Fig. 2 shows the working procedure of the Ultrasonic Sensor HC-SR04.

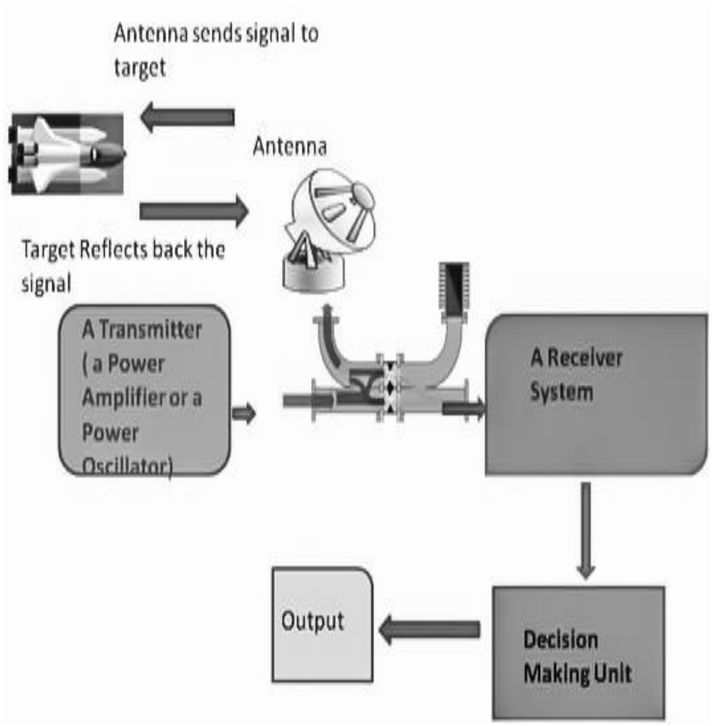

Fig. 1. Working procedure of RADAR system (RADARsystem, 2013)

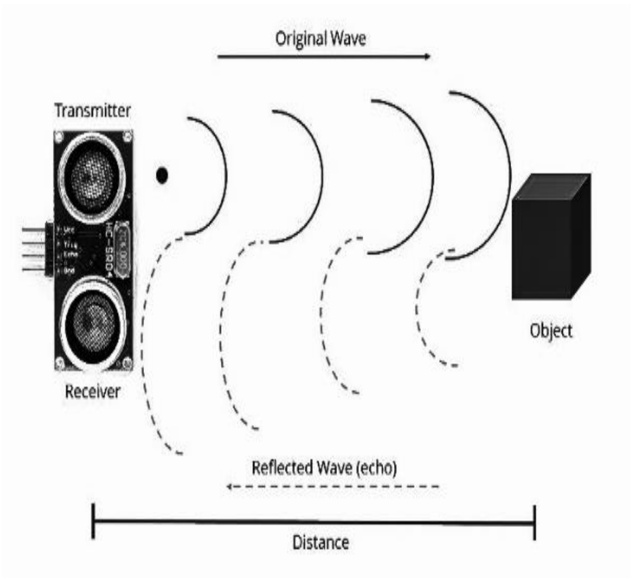

Fig. 2. Working procedure of ultrasonic sensor HC-SR04 system (Ultrasonic Sensor HC-SR04 System, 2013)

2. LITERATURE REVIEW

The use of radar system in research field increasing day by day. Sairam et al., (2018) proposed a system using LPC2148, DC geared motor and ultrasonic sensors that can detect object and human in still or motion, several research works also done like in paper (Soni et al., 2017), a distance measurement system developed by using Arduino and ultrasonic sensor as well as in paper (Onoja et al., 2017), a radar system has been developed that can detect distance and direction of object with a processing App. Also, Iyer et al., (2018), proposed a distance and direction measurement by using an Arduino ultrasonic radar embedded system. Maurya et al., (2016), developed a distance and direction detection system by using a microcontroller and a height detector with ultrasonic sensor by using a microcontroller ATmega16 developed by Sreeja et al., (2018).

Shih-An et al., (2012) used several servo motors to operate the manipulators to control the movement of robotics arms. In a similar manner, the servo motor is used to regulate the motion of the ultrasonic sensor that is connected to it. In every field security is the essential part. According to Yadav et al., 2018), employing inexpensive methods to detect objects is a difficult task. Internet of Things (IoT) components like ultrasonic sensors and servo motors are significantly affordable devices for object detection.

Patkar et al., (2016) employed a horizontal array of ultrasonic sensors to detect objects, since these are inexpensive devices. Using radar and ultrasonic signal, road surface recognition is done by Aleksandr et al., (2014). In a similar way, a single ultrasonic sensor can be used to determine the distance between several objects. Since the signal loss is less, ultrasonic sensors are employed in (Wobschall et al., 2005) by Darold et al. to measure distance. We can also determine the object distance because ultrasonic sensors can be used for measure distance.

Eugin et al., (2015) developed short range ground surveillance radar that's uses FMCW (Frequency Modulated Continuous Wave) to detect the moving objects. This FMCW enabled short range ground surveillance radar is quite expensive. Therefore, Internet of Things (IoT) components like servo motors and ultrasonic sensors may be utilized to detect the objects. Shao et al., (2018) developed a method to calculate the parking space based on the vehicle's width using ultrasonic sensor. Vehicles and their distance from the sensor may both be detected using and ultrasonic sensor.

Groeningen et al., (2018) used ultrasonic sensor to detect the presence of human in a smoke-filled environment. Jahangir el al., (2013) detected the height of an object by using ultrasonic sensor connected with a smartphone. In paper (Reddy et al., 2016), the length of an object could also be detected by using an ultrasonic sensor combined with Raspberry Pi. Another system can detect more than one object position (Majchrzak et al., 2009). In paper (Jain et al., 2017), to cover a large range of ultrasonic sensor and turned into a mobile robot with a sonar system, a radar system can also be developed.

Above all the papers discuss about radar system instead of ultrasonic sensor and microcontroller with along any of the Internet of Things (IoT) integrated information sending modules like GPS-GSM SIM808, but the proposed research work provides easy, affordable, and effective solution.

3. METHODOLOGY

This section gives brief explanation on experimental setup, hardware analogy, algorithms, equations, block diagram, and flow chart.

3.1 Experimental Setup

An ultrasonic sensor is employed instead of RADAR because it is less expensive and simpler to use. It produces sound waves, which are reflected back when they hit an object, after detect that object they reflect back. Servo motor is used for rotating the ultrasonic sensor in 180°. Arduino Uno is now used to process this data, or to convert it from analog to digital. SIM808 is used, which is connected to Arduino Uno, to send an SMS or message alerting the user of the object detection. The data has been sensed and processed, but Raspberry Pi3 is used to monitor and access it. Therefore, every piece of hardware, including the SIM808, servo motor, and ultrasonic sensor, is connected to Arduino Uno, which is then connected to the Pi 3. Jumper wires are used to connect the Pi3's input devices, including the keyboard, mouse, and monitor. The physical devices and hardware connections are made, but without software to monitor the output, results aren't possible. Raspbian or Noobs OS must first be installed on the Raspberry Pi 3 in order to interact or interface. To program the code in C/C++, Arduino IDE is installed. The Processing IDE is used to build the graphical user interface in Java. The code is used to run the devices in order to make the proposed work possible and to monitor the outcomes as well as to observe the object that has been detected in the java-based graphical user interface with the help of ultrasonic sensor and to send SMS messages from the SIM808.

3.2 Hardware Analogy

Initially, the Pi3 is fitted with an SD card for storage that contains Noobs or Raspbian OS. Keyboards, mouse, and monitors are connected to the Raspberry Pi 3. Put a 4G SIM card into the SIM808 that has the internet and SMS features enabled. Connect the GSM and GPS antennas. Now, connect the GND(Power/Analog In) of Arduino Uno to SIM808 GND, (Digital In) Tx(8) of Arduino Uno to Rx of SIM808, Rx(7) of Arduino Uno to Tx of SIM808, GND of Ultrasonic sensor to GND(Power/Analog In) of Arduino Uno, Trig of Ultrasonic sensor to 11 of Arduino Uno, echo of Ultrasonic sensor to 12 of Arduino Uno, Vcc of Ultrasonic sensor to 5v(Power/Analog In) of Arduino Uno and each of servo motor's wire to 9, 5v, GND of Arduino Uno respectively. Jumper wires are used to connect the Arduino Uno, servo motor, ultrasonic sensor, and SIM808. Now use a USB cable to connect Arduino Uno and Raspberry Pi3. Next, connect the SIM808 and Raspberry Pi3 to an adaptor to turn them on. The detailed connection in a pictorial representation is given in Fig. 3.

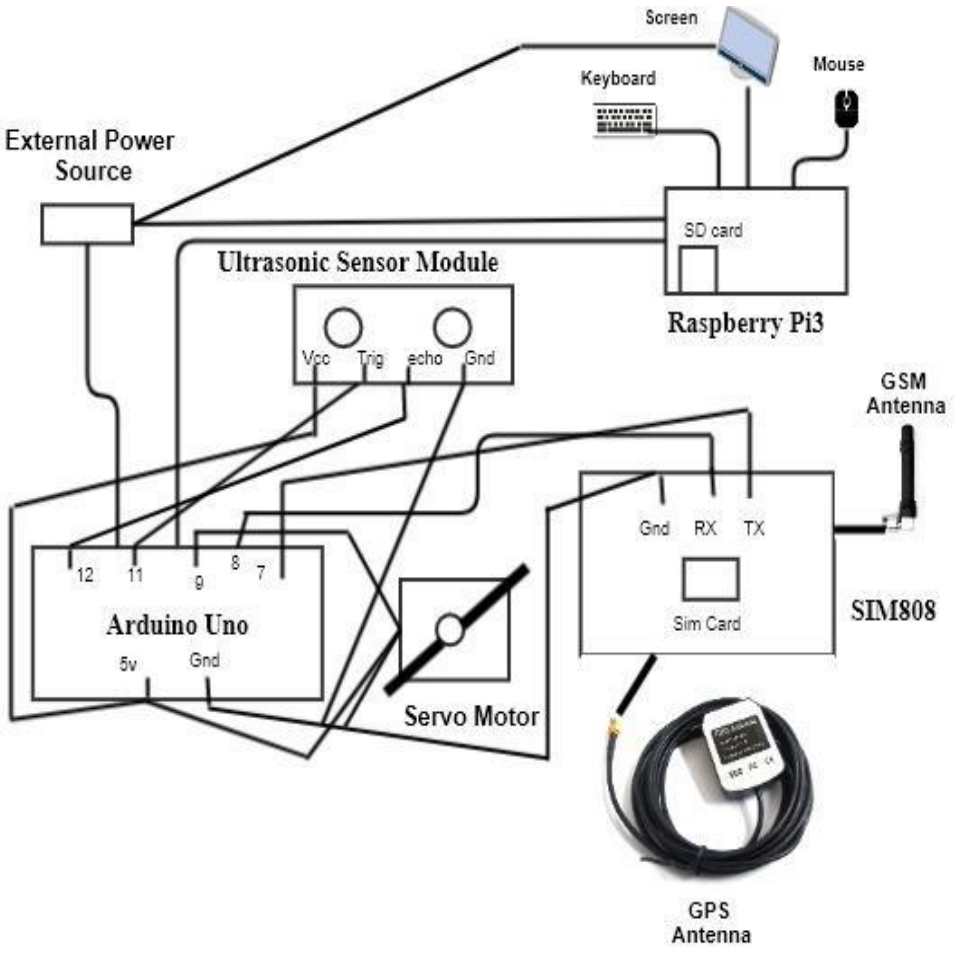

Fig. 3. Hardware connection setup of the proposed system

3.3 Algorithms

The trig pin and echo pin of the ultrasonic sensor, which are connected to Arduino pins 11 and 12, are declared before to the setup function. The pinmodes of trigpin and echopin are set to output and input, respectively, in the setup function. Identifying the pin at 9 to which the servo motor is connected. The SIM808 is then initialized for operation using a sequence of AT commands, such as AT+CMGF=1 and AT+CGNSPWR=1, and the baud rate is set to 9600. The loop function is used to running the part of the code n number of times. Here, a for loop with a delay of 30 milliseconds is used to rotate the servo from 15 to 165 and 165 to 15 degrees. Then in order to determine the distance that the ultrasonic sensor measured for each degree, the compute Distance function is called. The trigpin in this function is initially low for two microseconds. Next, to transmit high-frequency sound signals, trigpin is set to high for ten microseconds, and then it is set to low for two milliseconds. When the echopin is set high, it reads the signals and functions as a transmitter, returning the sound wave travel time in microseconds to the variable duration. This is why there are delays. The distance is then calculated as: duration * 0.034/2. If the object is within the detection range, then through AT command AT+CMGS = number, range, and angle of the object detected is sent via SMS. This whole part is about detecting the object. The processing of the RADAR GUI to observe object detection is covered in the next section of the Java code. "The code includes importing the libraries needed for reading data from the serial port and for serial communication. Next, define the serial object and the variables for calculating the angle, distance, and object detection. Now, define the GUI's pixel size in the setup function, start the serial communication by defining the COM port to which arduino is connected and read the data from the serial port. In function draw, simulate motion blur, slow fade of the moving line and call functions to drawRadar, drawLine, drawText, drawObject. In function drawRadar, arc lines and angle lines are drawn. In function draw Object, set the range of the sensor to detect the object, calculate distance and angle, mark the object detected in red color and fade it to black color and if no object detected, then mark it in green color. In function drawLine, lines at particular angles are drawn and in drawText, required texts for displaying angles in degree range in cm and detection of object is defined" (Bystrov et al., 2014; Wobschall et al., 2005).

- **Step 1: Start and initiate the code**
- **Step 2: Initialize all variables: trig pin, echo pin, distance, distance1, distance2, speed, angle, duration and pulse duration**
- **Step 3: Set the pin mode, defining trig pin as output and setting echo pin as an input. Without defined pin setup, it is not possible to start the work**
- **Step 4: Start the loop in order to start counting the angle for loop: declare i=15; where i<=165; increment the value of i by one**
  - **a) Write value for servo: servo write (i)**
  - **b) Set the delay for the rotation; to control the speed of servo motor**
  - **c) Read the distance and keep it in the variable distance1**
  - **d) Set the duration between reading of two distances: delay (1000)**
  - **e) Read the distance and keep it in the variable distance2**
  - **f) Calculate the speed : speed = (distance1-distance2) / 1.0**
  - **g) Print the outputs in serial monitor: distance, angle, speed and pulse duration.**
  - **h) End of the loop**
- **Step 5: Start the loop for moving to the starting point:**
  For loop: declare variable i=165; where i>15; decrement variable i by 1 (because now servo motor goes from 165 degrees back to 0 degree). Again, it would follow the sub steps of the step 4 in search of the object.
- **Step 6: Call the function 'distance'**
  - **a) set the trig pin**
  - **b) set the delay**
  - **c) find the duration, duration = pulseIn (echoPin, HIGH);**
  - **d) find the distance, distance= duration*0.034/2;**
  - **e) print object detected**
  - **f) send distance, angle and speed of the object via SMS**
  - **e) return distance**
- **Step 7: End procedure**

Fig. 4. Algorithms of the proposed system

$$D = \frac{T * 0.034}{2} \quad (1)$$

$$v = \Delta d \div \Delta t = \frac{d2 - d1}{t2 - t1} \quad (2)$$

$$e = \frac{du - da}{da} * 100 \quad (3)$$

$$\eta = 100 - e \quad (4)$$

Fig. 5. Equations of the proposed system

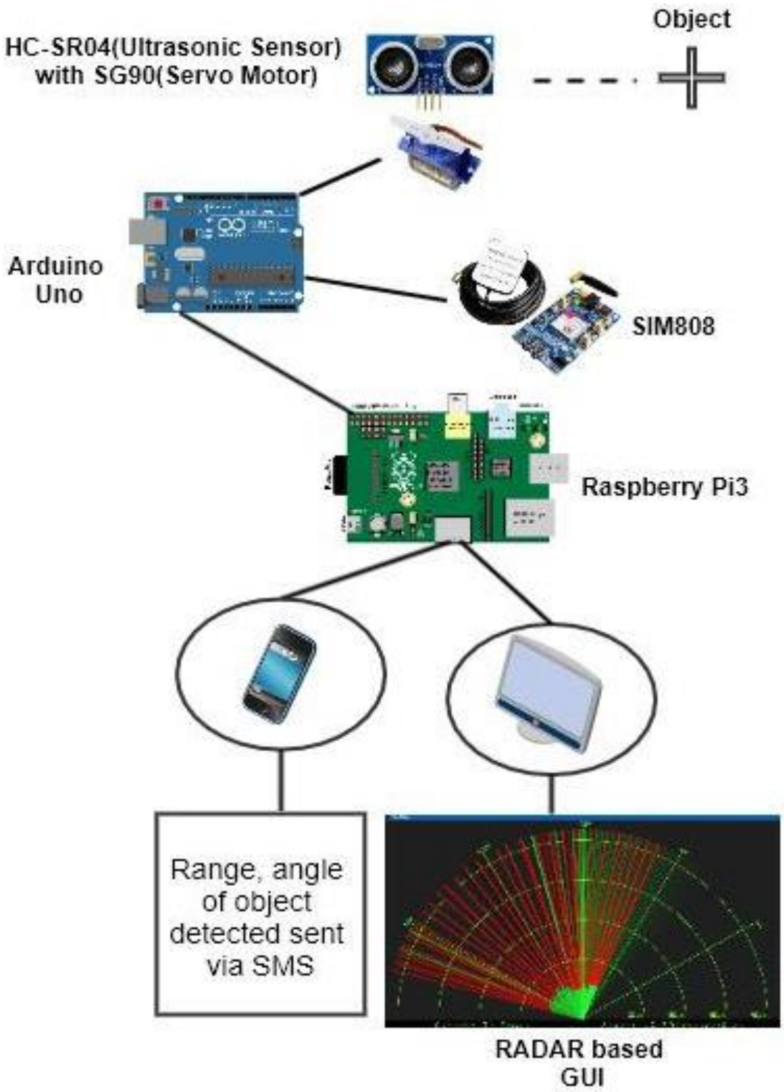

Fig. 6. Block diagram of the proposed system

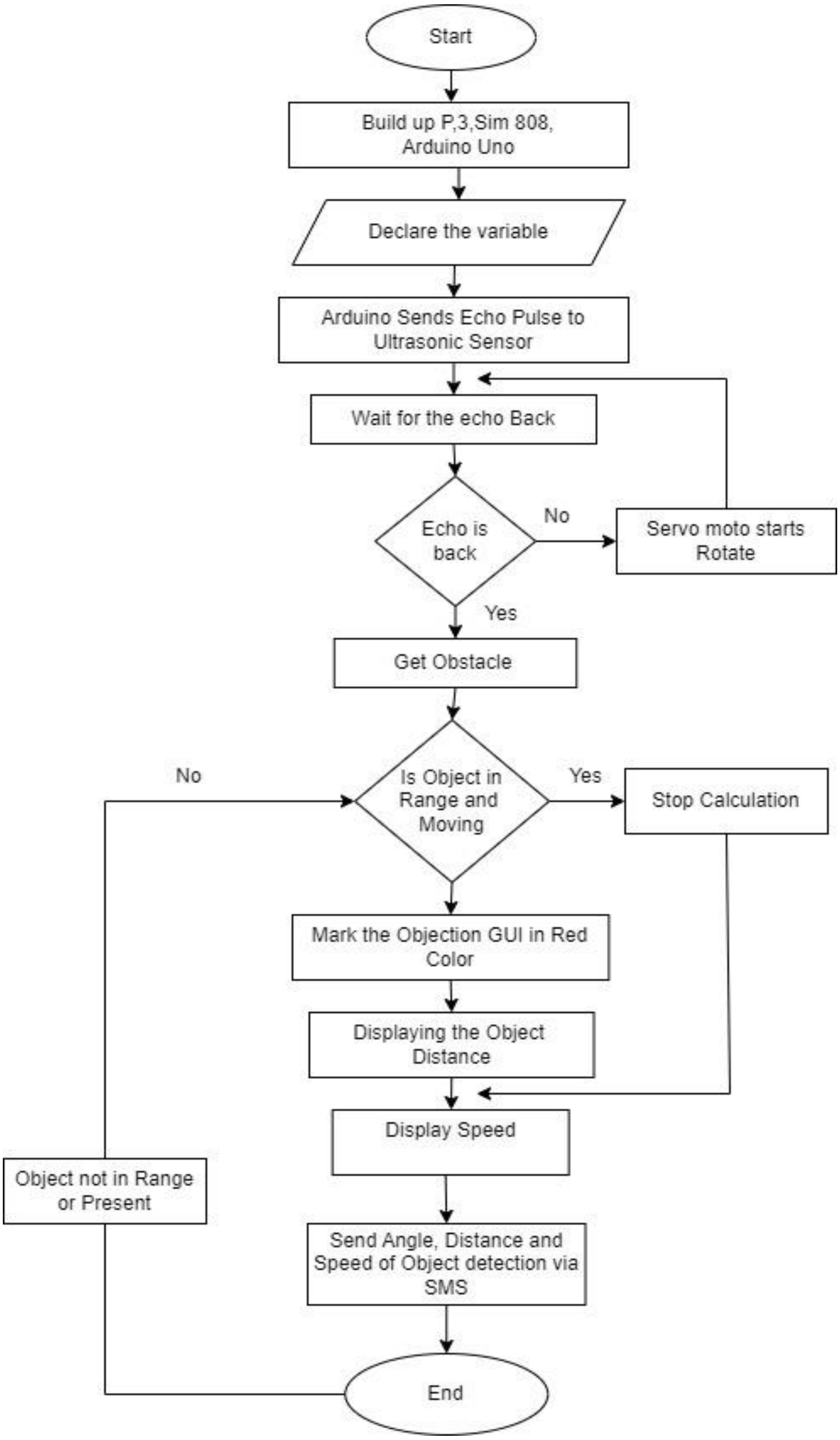

Fig. 7. Flowchart of RODDMS-IoT

3.4 Equations

The equations are shown in (1), (2), (3) and (4). From equation (1), distance is denoted by the symbol D and duration or travelling time of echo pulse is denoted by the symbol T. In equation (2), velocity of the object is V, Δd is the difference between two distances, Δt is the time difference for displacement of the object, d2 is the final distance of the object, d1 is the initial distance of the object, t2 is the final time of the displacement, and t1 is the initial time of the displacement. In equation (3), the error between the two distances (%) is denoted by the symbol e, du represents the ultrasonic distance, and da represents the actual distance. In equation (4), the efficiency of the ultrasonic sensor (%) is denoted by the symbol η.

3.5 Block Diagram

Fig. 6 gives the Block diagram of the proposed work in which the working of the system can be easily recognized. Fig. 10 gives the process flow of the work carried out which includes making connections, powering up the components, placing the object in front of the sensor for detection at different set of ranges and if in range then mark it in red color, send range and angle of the object detected and distance measured via message/SMS. Thus, the work provides easy and cheap method for object detection and distance measurement.

3.6 Flowchart

Fig. 7 shows the overall flowchart of the proposed system which is object detection and distance measurement system using IoT.

4. RESULTS AND DICUSSION

This section explains about the experimental outcomes and graphical representations.

4.1 Experimental Outcomes

This section explains about the outcome of the work done. Fig. 8, Fig. 9, Fig. 10 gives the screenshot of different sets of RADAR based GUI. Fig. 8 shows the green lines which depicts that no object is kept in front of the sensor or it may be outside the range with angle mentioned as 56°. Fig. 9 shows the object detected in red color with the range in 8 cm and angle at 65°. Fig. 10 shows the object detected in red color fading to black color as the arcs move (servo motor moves/rotates) in range of 40 cm and angle at 100°. Fig. 11 shows the screenshot of the output of range and angle of the object detected. Fig. 12 gives the screenshot of the message/SMS sent to the given number when the object is detected with its angle, distance and speed.

During the implementation of the experiment, the serial monitor continuously produced data. There were in total of 18 data sets collected for evaluation and validation checking, as shown in Table 1. The result shows whether the object is static or moving. If the object is moving towards the radar then it produces a negative value and vice versa. If the object is static, then the speed is zero. With this, the system is able to locate a moving object. Table 1 shows the results of a non-metal square 3D object. Object distance was increased with various speeds to observe the validity of algorithm. The serial monitor output shows the three important parameters angle, distance and speed.

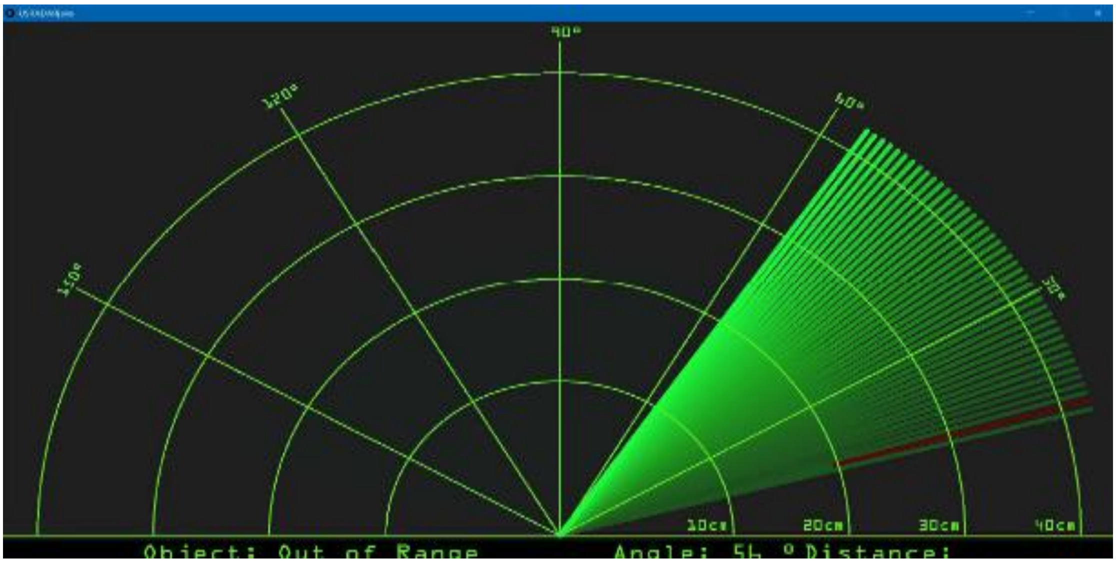

Fig. 8. No Object detected

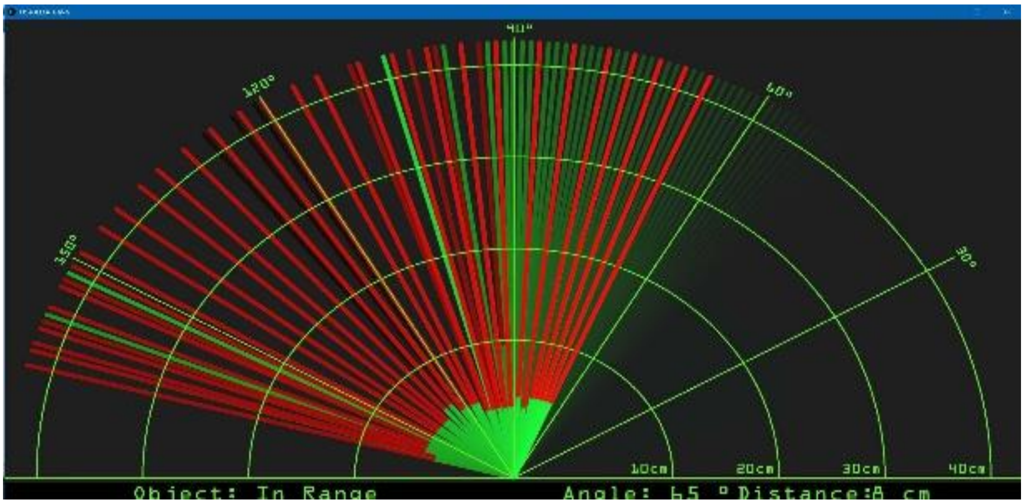

Fig. 9. Object detected

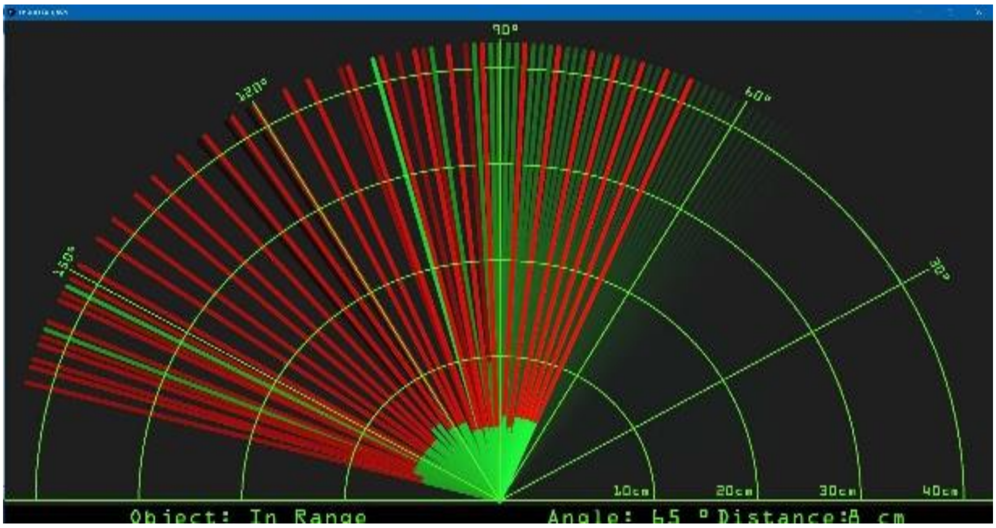

Fig. 10. Object detected (fade)

Fig. 11. Output of object detection and distance measurement

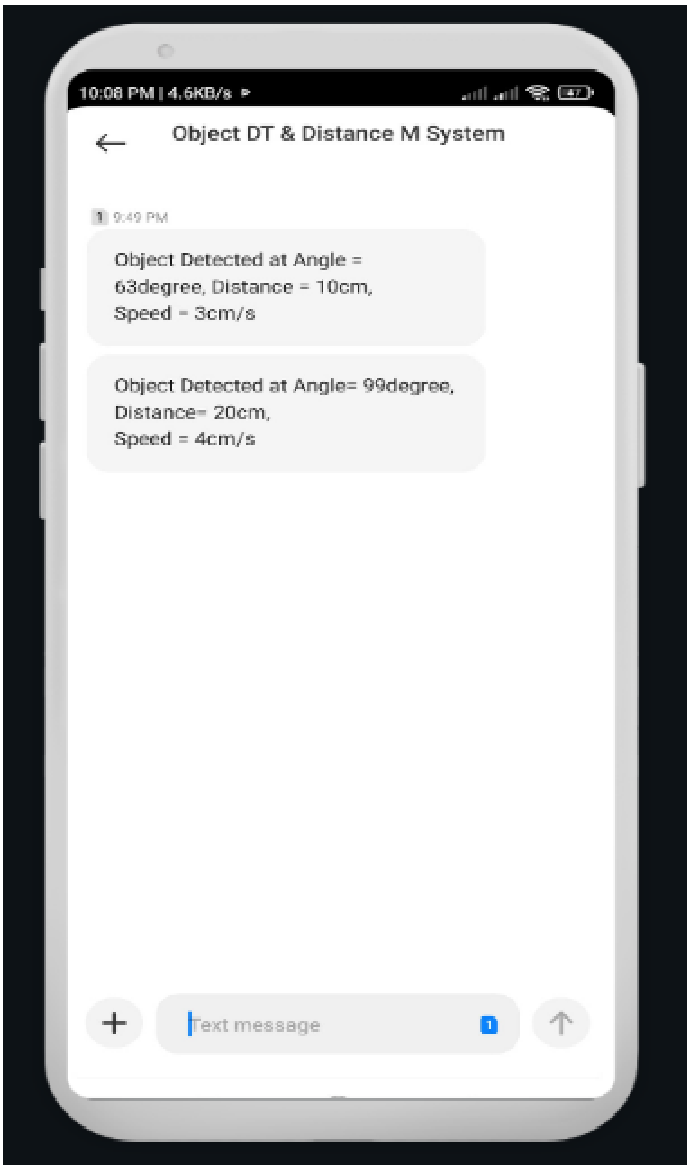

Fig. 12. Screenshot of object detection and distance measurement through SMS

Table 1. Object observation in different angle, distance and speed

Angle (cm/s)	Distance (cm/s)	Speed (cm/s)
42	6	-3.00
62	9	-3.00
63	10	3.00
81	12	0.00
79	13	1.00
86	14	0.00
22	15	-9.00
98	16	-1.00
97	17	0.00
99	20	4.00
101	22	1.00
103	23	1.00
105	24	1.00

Angle (cm/s)	Distance (cm/s)	Speed (cm/s)
106	25	1.00
113	36	-1000
117	70	-17.00
118	81	12.00
122	110	-921.00

Table 2. Distance measurement of proposed system for metal object

Ultrasonic Distance (cm) (Metal Object)	Actual Distance (cm) (Metal Object)	Efficiency (%) (Metal Object)	Error (%) (Metal Object)
3	2	50.00	50.00
3	2.7	88.89	11.11
4	3.5	85.71	14.29
5	4.5	88.88	11.11
6	5.5	90.00	9.09
7	6.6	93.93	6.06
7	6.8	97.44	2.56
8	7.8	100.00	2.56
9	9	100.00	0.00
10	10	100.00	0.00
11	11	100.00	0.00
12	12	100.00	0.00
13	13	100.00	0.00
14	14	100.00	0.00
15	15	100.00	0.00
18	18	100.00	0.00
20	20	100.00	0.00
30	30	100.00	0.00

Table 3. Distance measurement of proposed system for non-metal object

Ultrasonic Distance (cm) (Non-Metal Object)	Actual Distance (cm) (Non-Metal Object)	Efficiency (%) (Non-Metal Object)	Error (%) (Non-Metal Object)
3	2.5	63.63	36.36
4	3	66.66	33.33
5	4	75.00	25.00
5	4.5	88.88	11.11
6	5.8	96.55	3.44
7	6.8	97.06	2.94
8	7.9	98.73	1.27
9	9	100.00	0.00
10	10	100.00	0.00
12	12	100.00	0.00
13	13	100.00	0.00
14	14	100.00	0.00

Table 2 and Table 3 are constructed from data which was taken from the radar readings. The actual values of object's distances were measured inside the room for both metal and non-metal objects, showing the actual and the ultrasonic distance. From this, efficiency and error are calculated to evaluate the performance of connection setup using equation (3) and equation (4).

4.2 Graphical Representations

Fig. 13 is a comparison between the two efficiencies of metal and non-metal objects. For the first stages of the graph the difference is larger and when the distance increased, the fluctuation is decreased. It should be noted that efficiency performances are not same for metal and non-metal objects.

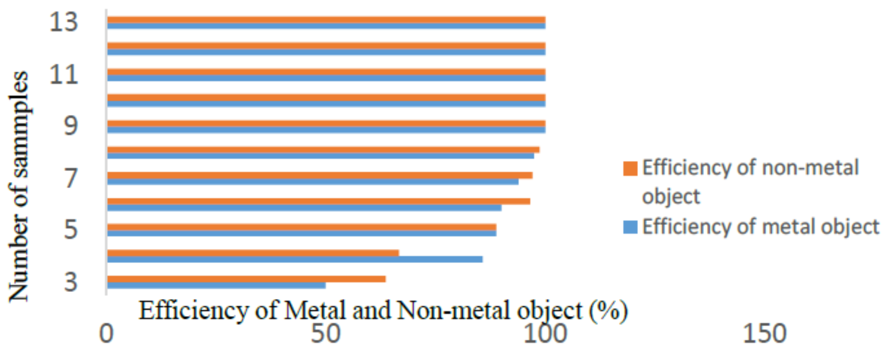

Fig. 13. Efficiency of metal and non-metal object of the proposed system

5. CONCLUSION AND FUTURE WORKS

In this paper, the work i.e. RADAR based Object Detector using Ultrasonic Sensor has been successfully carried out. It gives solution for easy object detection with ultrasonic, working like RADAR instead of using actual RADAR which is costly and tough to handle. “The work included IoT devices and software for the connection. Data was processed by the Raspberry Pi3 computer and Arduino Uno board. Object detection was done via Ultrasonic sensor with servo motor attached to the boards and the distance, angle, timestamp of object detected was sent to the given number via SMS/message using SIM808 module. Therefore, the work provides easy to setup and handle solution for object detection as there is lot of advantages of ultrasonic over RADAR as mentioned in the introduction section. Overall, the system can provide 100% efficiency unless of the distance is less than one centimeter and the size is extremely small. However, it’s important to note that the experiment was done in a constant environment” (Shao et al., 2018).

In future, artificial intelligence, computer vision and machine learning techniques can be implemented to this research work. Also, higher range ultrasonic sensor can be used with 360 degree angle rotation for large area coverage. Different types of camera can be fixed to identify the object clearly.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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