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Ultrasonic Radar: An Arduino Based Object Detection and Distance Mapping System

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ABSTRACT
This paper presents the design and development of an Ultrasonic Radar system based on the Arduino Uno microcontroller, the HC-SR04 ultrasonic distance sensor and the SG90 servo motor. Radio Detection and Ranging (RADAR) was originally developed using radio waves to determine the range, position, or speed of objects. However, conventional radar requires a relatively long acquisition time, has a short recognition range, is not target-specific because of its wide beam, and is comparatively expensive and oversensitive. A more affordable, simple and effective alternative is to use an ultrasonic sensor, which uses sound waves for ranging and detection. This paper presents a procedure in which the Ultrasonic Sensor (HC-SR04) acts as the RADAR unit. The HC-SR04 is mounted on a Servo Motor (SG90) for rotation/sweeping. These parts are interfaced with an Arduino Uno, which is programmed to detect and indicate the position of an object. Typically, the operating frequency of ultrasonic waves is around 20 kHz, but the HC-SR04 used here operates at 40 kHz with a detection range of 2 cm to 400 cm, making it well suited for short-range detection tasks.
The proposed system utilizes high-frequency ultrasonic sound waves to detect and measure the distance of objects within its operating range. The ultrasonic transmitter and receiver module is interfaced with the Arduino microcontroller, which processes the time-of-flight data to calculate the object distance in real time. A rotating servo motor provides scanning capability across an angular range of 0° to 180°, while the detected data can be visualized on a graphical interface that simulates a radar screen on a computer. This low-cost, non-invasive system has wide potential applications in robotics, obstacle-avoidance systems, automation, security and indoor environmental mapping.

Project Specifications

S. No.	Parameter	Value with Tolerances
1	Size	Sensor: ~45 mm x 20 mm x 15 mm; Servo: ~40 mm x 20 mm x 40 mm
2	Weight	Sensor: ~10 g; Servo: ~9-15 g
3	Input Voltage	HC-SR04: 5 V DC; Servo Motor: 4.8-6 V DC
4	Input Current	HC-SR04: ~15-30 mA during operation; Servo: ~100-250 mA (idle), up to 1 A (under load)
5	Frequency of Operation	40 kHz (ultrasonic pulse from HC-SR04)
6	Range of Detection	2 cm to 400 cm
7	Accuracy	+3 mm, -3 mm

8	Beam Angle	~15 degrees
9	Time of Flight	~58 µs per cm (round trip)
10	Update Rate	~20 Hz
11	Servo Scan Angle	0-180 degrees
12	Servo Speed	~0.1 sec/60 degrees at 4.8 V
13	Operating Temperature	HC-SR04: -15°C to 70°C; Servo: 0°C to 55°C

1. INTRODUCTION

In recent years, the demand for low-cost, intelligent sensing systems has grown rapidly across fields such as robotics, automation, security and navigation. A key requirement in these applications is the ability to detect obstacles and determine their relative position without relying on expensive radio-frequency radar hardware. Radar (Radio Detection and Ranging) was originally developed during World War II for detecting approaching aircraft using radio waves, and has since evolved into highly specialized military and civilian systems. However, conventional radio-wave radar is costly, oversensitive, and not suitable for short-range, low-power embedded applications.

An effective and economical alternative is the use of ultrasonic sound waves for object detection and ranging, an approach commonly referred to as 'ultrasonic radar'. This project focuses on the design and implementation of an Arduino-based ultrasonic radar system that integrates the HC-SR04 ultrasonic sensor with an SG90 servo motor. The ultrasonic sensor measures the distance of nearby objects by transmitting high-frequency sound pulses and calculating the time taken for the echo to return. To extend the sensing capability across a wider area, the servo motor rotates the sensor through an angular range of 0° to 180°, allowing the system to perform a directional sweep similar to a conventional radar display.

Arduino is an open-source electronics platform consisting of both hardware and software. Arduino boards can read inputs such as sensor signals and convert them into outputs such as motor movement or data transmitted to a computer. The board is programmed using the Arduino IDE, based on the Wiring/Processing languages, and the compiled code is uploaded to the microcontroller through a bootloader. Owing to its simplicity, open-source nature, low cost and large community support, Arduino was selected as the central processing unit for this project.

The combination of an ultrasonic sensor, a servo motor and an Arduino microcontroller result in a system that is simple to build, inexpensive, and effective for short-range obstacle detection and environmental scanning. The processed distance and angle data can be transmitted via the serial port to a computer, where it can be visualized as a radar-like sweep, making the system useful for educational purposes as well as for prototyping robotic navigation and obstacle-avoidance applications.

2. SYSTEM OVERVIEW

The proposed Ultrasonic Radar system is built around the Arduino Uno microcontroller, which coordinates the operation of the HC-SR04 ultrasonic sensor and the SG90 servo motor. The system continuously rotates the sensor across a predefined angular range while measuring the distance to nearby objects at each angular position, and transmits the combined angle-distance data for real-time visualization.

2.1 Overall System Architecture

The system consists of three main units: the sensing unit, the control unit, and the output/display unit. The HC-SR04 ultrasonic sensor forms the sensing unit, which detects the distance of objects in front of it. The Arduino Uno serves as the control unit, processing sensor data and generating the PWM control signals for the servo motor. The servo motor forms the actuation unit, providing directional sweeping, while the serial output to a computer (or an optional LCD/buzzer module) forms the display/alert unit.

2.2 Working Modules

The system can be divided into the following functional modules:

- Distance Measurement Module: Uses the HC-SR04 ultrasonic sensor to measure the distance between the system and nearby objects by calculating the echo time.
- Servo Motor Control Module: Controls the rotation of the ultrasonic sensor across an angular range of 0° to 180° using PWM signals generated by the Arduino.
- Processing and Control Module: The Arduino processes the distance data received from the ultrasonic sensor, synchronizes it with the current servo angle, and formats the combined data for output.
- Display/Alert Module: The processed angle-distance pairs are transmitted via serial communication for graphical radar-style visualization, and may additionally drive an LED/buzzer for proximity alerts.

2.3 Data Flow of the System

The operation of the system follows a sequential data flow:

1. The Arduino positions the servo motor at the starting angle (0°).
2. The HC-SR04 sensor sends a trigger pulse and waits for the echo signal.
3. The Arduino measures the time delay of the echo and calculates the corresponding distance.
4. The distance value is paired with the current servo angle and sent over the serial port.
5. The servo motor steps to the next angle, and the process repeats across the 0°-180° sweep.
6. On reaching 180°, the servo reverses direction and the sweep continue back to 0°, providing continuous scanning.

2.4 Key Features of the System

- Real-time distance measurement using the HC-SR04 ultrasonic sensor.
- 180-degree directional scanning using the SG90 servo motor.
- Radar-style visualization of detected objects on a computer screen.
- Simple, low-cost and easy-to-assemble design using readily available components.
- Suitable for real-time embedded and robotics applications.

3. COMPONENTS USED

The proposed system is built using a small number of low-cost hardware components that together achieve directional distance measurement and radar-style visualization. The main components used in this project are described below.

3.1 Arduino Uno

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The Arduino Uno is a microcontroller board based on the ATmega328P. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header and a reset button. It acts as the central processing unit of the system, controlling the servo motor through PWM signals, triggering the ultrasonic sensor, reading the echo response, calculating distances, and transmitting the angle-distance data over the serial port. The Arduino was chosen for this project due to its simplicity, low cost, flexibility and ease of programming through the Arduino IDE.

3.2 HC-SR04 Ultrasonic Sensor

The HC-SR04 is an economical ultrasonic distance sensor that provides non-contact distance measurement from 2 cm to 400 cm with a ranging accuracy of up to 3 mm. The module consists of an ultrasonic transmitter, a receiver and a control circuit, and has four pins: VCC (power), Trig (trigger), Echo (receive)
and GND (ground). The sensor measures distance by transmitting an ultrasonic pulse at 40 kHz and measuring the time taken for the echo to return using the formula Distance = (Time x Speed of Sound) / 2.

3.3 Servo Motor (SG90)

The SG90 is a small, lightweight micro servo motor capable of rotating from 0° to 180°. It is powered by a DC supply and controlled using PWM signals from the Arduino. In this project, the HC-SR04 sensor is mounted on the SG90 servo, which rotates the sensor across the angular range to enable directional scanning of the surrounding environment. The position of the servo is controlled precisely by varying the pulse width of the PWM signal generated by the Arduino.

3.4 Breadboard and Jumper Wires

A breadboard provides a convenient, solderless platform for connecting the Arduino, ultrasonic sensor and servo motor, allowing easy prototyping and modification of the circuit. Male-to-male jumper wires are used to make all the electrical connections between the Arduino, the HC-SR04 sensor, the servo motor and the breadboard power rails.

3.5 Power Supply

The system is typically powered through a 5 V supply, either directly from the Arduino's USB connection or from an external regulated 5 V source. The HC-SR04 sensor and SG90 servo both operate at 5 V. Since the servo motor can draw significant current under load, an external 5 V regulated power source sharing a common ground with the Arduino is recommended for the servo to avoid overloading the Arduino's onboard voltage regulator.

3.6 Buzzer and LED Indicators (Optional)

An optional buzzer and LED indicators can be added to the circuit to provide an audible and visual alert when an object is detected within a critical distance. These components connect to spare digital pins on the Arduino and are activated based on threshold comparisons performed in software.

Table 1: Bill of Material

Item	Quantity	Description
Arduino Uno	1	Microcontroller board
HC-SR04 Ultrasonic Sensor	1	Distance measurement sensor

Servo Motor (SG90)	1	Small hobby servo motor
Breadboard	1	Solderless prototyping board
Jumper Wires	~10	Male-to-male jumper wires
USB Cable	1	For powering and programming the Arduino
External 5V Power Supply	1 (optional)	For servo motor, if required

4. SOFTWARE IMPLEMENTATION

The software for the proposed system is developed using the Arduino Integrated Development Environment (IDE) and written in embedded C/C++. The program controls the servo motor, triggers the ultrasonic sensor, processes the returned echo time into a distance value, and transmits the angle-distance pair over the serial port for real-time visualization.

4.1 Programming Environment

The Arduino IDE provides a user-friendly interface for writing, compiling and uploading code to the Arduino Uno. The built-in <Servo> library is used to simplify control of the SG90 servo motor by allowing the rotation angle to be set directly in degrees, while standard digital I/O functions are used to interface with the HC-SR04 sensor.

4.2 Algorithm of the System

7. Initialize the servo motor, ultrasonic sensor pins, and serial communication.
8. Set the initial position of the servo motor to 0°.
9. Send a short trigger pulse to the HC-SR04 sensor.
10. Measure the duration of the returned echo pulse and calculate the distance using the speed of sound.
11. Transmit the current servo angle together with the measured distance over the serial port.
12. Increment the servo angle by a fixed step (e.g., 1° to 5°) and repeat steps 3-5 until 180° is reached.
13. Reverse the direction of rotation and repeat the sweep from 180° back to 0°.
14. Repeat the entire scanning process continuously.

4.3 Servo Motor Control Logic

The servo motor is controlled using Pulse Width Modulation (PWM) signals generated by the Arduino through the Servo library. The angle of rotation is determined by varying the pulse width applied to the control wire of the SG90. The program rotates the servo in small, fixed steps across the 0°-180° range, with a short delay introduced at each step to allow the servo to settle and the ultrasonic sensor to obtain a stable reading before the next measurement is taken.

4.4 Sensor and Data Processing

At each angular position, the Arduino sends a 10-microsecond HIGH pulse to the Trig pin of the HC-SR04. The sensor responds by emitting an ultrasonic burst and setting its Echo pin HIGH for a duration proportional to the time taken for the echo to return. The Arduino measures this duration using the pulseIn() function and computes the distance using the relation Distance (cm) = Duration (µs) / 58, since the ultrasonic pulse travels to the object and back (round trip) at approximately 58 microseconds per centimeter.

_4.5_ Data Visualization

The calculated distance, together with the corresponding servo angle, is transmitted via the serial port to a connected computer. A visualization program (developed, for example, in Processing or a similar graphical environment) reads this data and renders it as a rotating radar sweep, plotting detected objects at their corresponding angle and distance on a circular radar-style display.

_4.6_ Program Flow Control

The entire program operates within a continuous loop in which the servo sweeps back and forth across its angular range while the ultrasonic sensor takes a measurement at every step. Conditional statements are used to reverse the direction of the servo sweep once the angular limits (0° and 180°) are reached, ensuring smooth, repetitive scanning of the surrounding area.

_4.7_ Error Handling and Optimization

- Ignoring invalid or out-of-range sensor readings (e.g., readings beyond 400 cm or equal to zero).
- Introducing short delays between successive measurements to allow the ultrasonic pulse to settle and avoid cross-talk.
- Using consistent step sizes for the servo to maintain a uniform angular resolution across the scan.

5. WORKING PRINCIPLE

The working principle of the proposed system is based on the integration of ultrasonic distance measurement with servo-controlled directional scanning, coordinated entirely by the Arduino Uno microcontroller.

_5.1_ System Initialization

When the system is powered on, the Arduino initializes the servo motor, sets the HC-SR04 trigger and echo pins, and begins serial communication with the connected computer. The servo motor is moved to its initial position (0°), preparing the system for the first scanning cycle.

_5.2_ Directional Scanning Using the Servo Motor

The servo motor rotates the HC-SR04 sensor across the 0° to 180° angular range in small steps. At each step, the Arduino sends PWM signals to position the servo precisely, allowing the system to scan different directions in front of it.

_5.3_ Distance Measurement

At each angular position, the HC-SR04 sensor transmits an ultrasonic pulse and measures the time taken for its echo to return after reflecting off an object. The Arduino converts this time delay into a distance value using the speed of sound in air. This process is repeated continuously across the angular range to cover the entire scanning arc.

_5.4_ Data Processing and Output

The Arduino pairs each measured distance value with the corresponding servo angle and transmits this combined data via the serial port. On the connected computer, this data is used to generate a radar-style display showing the angle and distance of detected objects, effectively mapping obstacles within the scanning arc.

5.5 Continuous Operation

After completing a sweep from 0° to 180°, the servo motor reverses direction and sweeps back from 180° to 0°, continuously repeating this back-and-forth motion. This ensures real-time, continuous monitoring of the surrounding environment, allowing the system to detect changes such as moving objects entering or leaving the scanning area.

6. WORKING MECHANISM

The working mechanism of the proposed system begins with powering the entire setup, which supplies electrical energy to the Arduino Uno, the HC-SR04 ultrasonic sensor and the SG90 servo motor. Once powered on, the Arduino initializes all connected components and positions the servo motor at its starting angle.

The ultrasonic sensor is then triggered to detect the presence of objects in front of it. It operates by transmitting ultrasonic waves and receiving the reflected echo signals from nearby objects. Based on the time taken for the echo to return, the Arduino calculates the distance of the object. This calculated distance value is processed in real time and prepared for transmission to the visualization software.

Simultaneously, the servo motor plays a crucial role in locating the position of the object. The Arduino sends Pulse Width Modulation (PWM) signals to the servo motor, causing it to rotate the ultrasonic sensor across the predefined angular range. As the servo rotates, the system scans different directions and detects objects at various angles.

By combining the angle of the servo motor with the measured distance, the system determines the relative position of any detected object within its 180° field of view. The resulting angle-distance pairs are transmitted continuously over the serial port, where they are plotted in real time on a radar-style graphical display, effectively recreating the sweeping behaviour of a conventional radar screen using ultrasonic sensing.

Thus, the system continuously performs scanning, detection, calculation and data transmission operations in a loop, enabling real-time range finding and directional positioning of objects within its operating range.

7. RESULTS AND ANALYSIS

The developed Arduino-based ultrasonic radar system was successfully implemented and tested under various conditions. The system demonstrated reliable performance in terms of distance measurement, servo-based scanning, and real-time radar-style visualization.

7.1 Distance Measurement Performance

The HC-SR04 ultrasonic sensor accurately measured the distance of objects placed at various ranges between 2 cm and 400 cm. The measured values were transmitted in real time and were found to be stable and consistent within the effective range of the sensor. Minor variations were observed due to environmental factors such as surface type, material softness, and the angle of reflection of the target object.

7.2 Servo Motor Scanning Performance

The SG90 servo motor successfully rotated the ultrasonic sensor across the defined angular range of 0° to 180°. The scanning motion was smooth and continuous, allowing the system to detect objects in multiple directions. The synchronization between the servo movement and

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the sensor readings ensured that distance measurements were correctly associated with each angle, with the angular resolution depending on the chosen servo step size.

7.3 Radar Visualization Output

The angle-distance data transmitted over the serial port was successfully visualized as a rotating radar sweep on a computer screen, with detected objects appearing as marked points at their corresponding angle and distance. The visualization updated in real time as the servo completed each sweep, providing an intuitive representation of the surrounding environment similar to a conventional radar display.

7.4 Overall System Performance

The overall system operated efficiently, with the Arduino Uno, HC-SR04 sensor and SG90 servo motor working in close synchronization. The system continuously performed scanning and data-transmission operations in real time without major errors during testing.

7.5 Observations

- Accurate distance measurement within the sensor's effective range (2 cm to 400 cm).
- Smooth, repeatable servo-based scanning across the full 0°-180° arc.
- Reliable, real-time radar-style visualization of detected objects.
- Stable serial communication between the Arduino and the visualization software.
- Low overall system cost using readily available components.

7.6 Limitations Observed

- Reduced accuracy when detecting soft, curved, or angled surfaces that absorb or deflect sound waves.
- Maximum effective range limited to approximately 400 cm.
- Scanning speed limited by the mechanical response time of the servo motor.
- Angular resolution dependent on the chosen servo step size; large steps reduce scanning detail.
- The system operates only in two dimensions unless an additional servo is added for vertical sweeping.

8. CONCLUSION

The proposed Arduino-based Ultrasonic Radar system has been successfully designed and implemented using an HC-SR04 ultrasonic sensor and an SG90 servo motor. The system is capable of measuring the distance of nearby objects while simultaneously scanning across a 180° field of view, and the resulting angle-distance data can be visualized in real time as a radar-style sweep on a computer screen.

The Arduino Uno efficiently coordinates the ultrasonic sensor and servo motor, demonstrating reliable real-time distance measurement, smooth directional scanning, and clear data transmission for visualization. Overall, the project achieves its objective of providing a low-cost, simple and effective alternative to conventional radio-wave radar for short-range object detection and mapping. The system serves as a strong foundation for applications such as obstacle detection, robotic navigation, security monitoring, and as an educational tool for teaching embedded systems and sensor-based automation.

9. FUTURE SCOPE

Although the system performs effectively, several enhancements can be made to improve its performance and extend its range of applications:

- 3D Mapping Capability: Adding a second servo motor for vertical movement can extend the system to perform 3D environmental scanning.
- Integration with GPS or IMU Sensors: Merging data from GPS or Inertial Measurement Units could enable dynamic environmental mapping and navigation in outdoor or mobile robotic systems.
- Wireless Communication: Using Bluetooth, XBee, or Wi-Fi modules to wirelessly transmit radar data to a remote monitoring system or control station.
- Obstacle Avoidance in Autonomous Systems: The system can be embedded into autonomous drones, cars, or robots for dynamic obstacle detection and avoidance.
- Real-Time Visual Display with Advanced GUI: Development of more advanced graphical interfaces (using Processing, Python, or MATLAB) to represent radar data interactively.
- Multiple Sensor Fusion: Combining multiple HC-SR04 sensors at different orientations can reduce blind spots and improve accuracy and scanning speed.
- AI Integration: Applying machine learning techniques for object recognition and intelligent decision-making based on detected patterns.

In terms of applications, this ultrasonic radar system has wide practical use across multiple domains. In robotics, it can be used for obstacle detection and navigation, enabling autonomous robots to move safely within their environment. In the automotive sector, it can serve as a low-cost parking-assistance or collision-detection system. In industrial automation, it can be used for object detection on conveyor belts or in automated sorting systems. It can also be employed in security and surveillance systems to detect intrusions or monitor restricted areas, and in drones/UAVs for altitude sensing and obstacle avoidance during low-altitude flight. Owing to its simplicity and affordability, the system also serves as an excellent educational tool for teaching concepts in electronics, embedded systems and sensor-based automation.

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