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A Miniature Radar for Detecting Objects Around and Measuring Distance for Short Range Applications

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Abstract: *This paper delineates the development of Radar (Radio Detection and Ranging) for object detection and distance measurement. Radar has garnered considerable attention across multiple domains, owing to its durability and dependability in varied environmental circumstances. The capability of radar to function proficiently in low visibility conditions, including fog, rain, or darkness, renders it an essential technology in autonomous systems, automotive applications, and robots. Radar systems ascertain the distance to objects by emitting radio waves and evaluating the time delay of the reflected waves. The capability of radar to identify distant objects and precisely ascertain their location has considerable ramifications for enhancing the safety and effectiveness of diverse systems. The current study employs a scaled-down version of the actual Radar that functions on the same operational premise. This compact Radar variant is constructed utilizing an Arduino Uno microcontroller, an ultrasonic sensor, a servo motor, an LCD screen, and additional peripherals. Its cost-effective implementation and simplicity of application render it highly beneficial for many small-scale appliances. The system installation is simple and yields accurate results.*

Keywords*:* Radar, Object detection, Distance measurement, Arduino

I. INTRODUCTION

Radar (Radio Detection and Ranging) technology has become increasingly integral in modern sensing applications due to its robustness in diverse environments, its ability to work in poor visibility conditions (such as fog, rain, or darkness), and its capacity for high precision in object detection and distance measurement [1]. In recent years, radar has seen widespread adoption across various domains, including autonomous vehicles, robotics, surveillance systems, and industrial automation. This is primarily because radar systems can operate reliably over long ranges, provide real-time data, and deliver valuable spatial information about objects in their environment. Object detection and distance measurement are two of the most critical tasks enabled by radar systems, particularly in dynamic environments where objects may be moving at varying speeds or be partially obscured by environmental clutter. In autonomous driving, for example, detecting and measuring the distance of nearby vehicles, pedestrians, or obstacles is essential for safe navigation and collision avoidance [2]. Similarly, in industrial settings, radar can be used for proximity sensing, equipment monitoring, and detection of foreign objects in assembly lines. At the core of radar's functionality is its ability to emit electromagnetic waves, which propagate through space and interact with objects. These waves are reflected back to the radar system by objects, and the system can then process the time it takes for the waves to return [3]. The delay in the return signal enables accurate distance measurement, while further analysis of the signal can provide information about the object's size, shape, speed, and other characteristics. There are various radar technologies, including Continuous Wave (CW) Radar, Frequency Modulated Continuous Wave (FMCW) Radar, and Pulse Radar [4].

Recent advancements in the use of radar for object detection and distance measurement, focusing on the methodologies, challenges, and solutions identified by scholars and engineers in the field. Radar systems measure the distance to

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objects by transmitting radio waves and analyzing the time delay of the reflected waves. This fundamental principle is applied across various radar technologies, including Continuous Wave (CW) Radar, Frequency Modulated Continuous Wave (FMCW) Radar, and Pulse Radar. Zhou et al. [5] explained about the network structure adapted in radar. They summarised three overlooked challenges in deep radar perception, including multi-path effects, uncertainty problems, and adverse weather effects, and present some attempts to solve them. Fishler et al. [6] proposed statistical MIMO radar concept, inspired by recent advances in multiple-input multiple-output (MIMO) communications. The primary distinction between statistical MIMO and other radar array systems is that the latter aim to optimize coherent processing gain, whereas statistical MIMO radar leverages target scattering diversity to enhance radar performance. While radar offers numerous advantages, several challenges persist in real-world applications. Environmental Factors such as rain, snow, and fog can attenuate radar signals, resulting in reduced detection accuracy. Various techniques for mitigating environmental impact, such as the use of adaptive signal processing algorithms that adjust to varying conditions in real-time [7]. Radar systems are highly sensitive to environmental clutter, such as nearby buildings or other objects that may result in false positives. Techniques such as Clutter Suppression and Multi-path Mitigation are explored by Jiang et al. [8], who emphasize the importance of filtering out non-relevant signals to improve object detection. Multi-Target Detection: Radar systems often face difficulties in distinguishing between multiple targets, especially in dense environments. Recent studies like Zhou et al. [9] focus on Multiple-Input Multiple-Output (MIMO) radar systems that utilize multiple antennas to improve detection of multiple objects simultaneously. To overcome the limitations of radar systems and improve accuracy, radar is increasingly being integrated with other sensing technologies, such as cameras and LiDAR. Sensor Fusion techniques combine data from multiple sensors to provide a more comprehensive and accurate representation of the environment. Research by Zhao et al. [10] and Xiao et al. [11] demonstrates how combining radar with optical sensors and LiDAR can significantly improve object detection accuracy and reliability, particularly in challenging environments with clutter or low visibility.

II. MATERIALS (SOFTWARE/HARDWARE)

A. Arduino UNO

The Arduino UNO R3 is an ideal platform for acquiring knowledge in electronics and programming. This multifunctional development board features the renowned ATmega328P and the ATMega 16U2 processor. This board provides an excellent introductory experience in the realm of Arduino. The Arduino UNO is a microcontroller board utilizing the ATmega328P. The apparatus consists of 14 digital input/output pins (6 of which facilitate PWM output), 6 analog inputs, a 16 MHz ceramic resonator, a USB interface, a power jack, an ICSP header, and a reset button. It encompasses all essential components for microcontroller operation; merely link it to a computer via a USB cable or power it with an AC-to-DC adapter or battery to commence activity. The UNO board gives freedom for experiments without much concern for errors; in the worst-case situation, the chip can be replaced for a nominal cost and begin anew. The Arduino Uno is an open-source microcontroller board based on the ATmega328P microchip, widely used for building electronics projects, prototypes, and experiments. It is one of the most popular boards in the Arduino family, known for its simplicity, versatility, and ease of use, making it ideal for both beginners and experienced developers. In summary, the Arduino Uno is a versatile, user-friendly microcontroller that serves as the foundation for a wide range of projects and applications, from simple circuits to more complex systems, all while being accessible to both beginners and experts.

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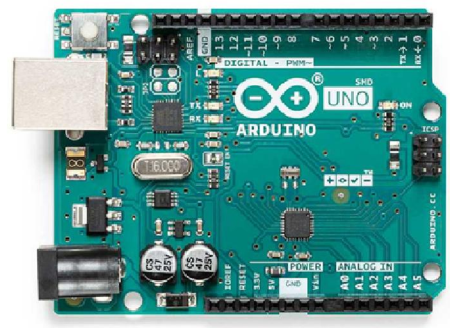

Fig. 1 Arduino Uno Microcontroller [12]

B. Servo motor

A servo motor is a motor capable of precise rotation. This motor type generally incorporates a control circuit that provides feedback on the current position of the motor shaft, allowing servo motors to rotate with exceptional precision. To rotate an object at specified angles or distances, a servo motor is employed. It consists solely of a basic motor operating via a servo mechanism. A motor powered by a DC power source is termed a DC servo motor, whereas a motor powered by an AC supply is referred to as an AC servo motor. In addition to these primary classifications, numerous other types of servo motors exist, categorized by gear arrangement and operational characteristics. A servo motor typically has a gear system that enables the acquisition of high torque in compact and lightweight configurations. Owing to these characteristics, they are utilized in various applications like as toy cars, remote-controlled helicopters and airplanes, and robotics.

Fig. 2 Servo motor [13]

C. Ultra sonic sensor

An ultrasonic sensor is an instrument that measures the distance to an object using ultrasonic sound waves. It is a device that employs a transducer to transmit and receive ultrasonic pulses, which convey information regarding an object's proximity. High-frequency sound waves reflect off boundaries, generating unique echo patterns. Ultrasonic sensors operate by emitting sound waves at frequencies above the threshold of human auditory perception. The sensor's transducer functions as a microphone to emit and detect ultrasonic sound. Our sensors, similar to many others, utilize a singular transducer to emit a pulse and capture the echo. The sensor calculates the distance to a target by monitoring the time intervals between the emission and reception of the ultrasonic pulse. This procedure is a fundamental component of ultrasonic sensor operation. The operational principle of this module is straightforward. It emits an ultrasonic pulse at 40 kHz, which propagates through the air, and if an impediment or object is present, it will reflect back to the ultrasonic sensor. The distance can be determined by calculating the travel time and the speed of sound. Ultrasonic sensors are an excellent solution for detecting transparent things. Applications utilizing infrared sensors for liquid level measurement

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encounter difficulties due to the translucence of the target. Ultrasonic sensors detect things for presence detection irrespective of color, surface, or material, unless when the material is exceptionally soft, such as wool, which absorbs sound. Ultrasonic sensors are a dependable option for detecting translucent and other materials where optical methods may be ineffective.

Fig. 3 HC-SR04 [14]

D. LCD

A liquid-crystal display (LCD) is a flat-panel display or electronically modulated optical device that utilizes the light-modulating characteristics of liquid crystals in conjunction with polarizers to convey information. Liquid crystals do not emit light directly; rather, they utilize a backlight or reflector to generate images in color or monochrome.

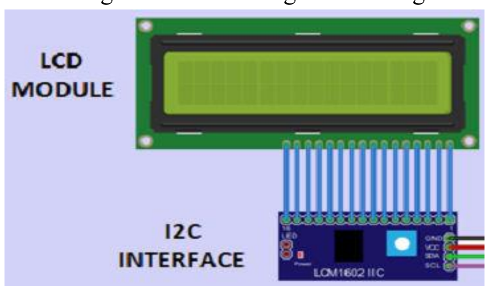

Fig. 4 LCD with I2C Interface [15]

E. BUZZER

Buzzer is a small yet efficient component to add sound features to our project/system. The component features a diminutive and tiny 2-pin configuration, facilitating its use on breadboards, perf boards, and PCBs, hence becoming it a prevalent choice in numerous electronic applications. Two types of buzzers are usually offered. The device depicted here is a basic buzzer that emits a continuous beep when powered, whereas the alternative version, known as a premade buzzer, seems bigger and produces a single beep. Sound generated by the internal oscillating circuit included within it. The circuit depicted here is the most commonly utilized due to its adaptability, allowing for customization with supplementary circuits to seamlessly integrate into our application. This buzzer operates by connecting it to a DC power supply with a voltage range of 4V to 9V. A standard 9V battery may suffice; however, it is advisable to utilize a regulated +5V or +6V DC power source. The buzzer is typically linked to a switching circuit to activate or deactivate the buzzer at specified times and intervals.

Fig. 5 Buzzer [16]

F. Tinker Cad

Tinkercad is a user-friendly, web-based application designed to help individuals create 3D designs, models, and electronics projects. It provides an intuitive interface, making it accessible to beginners, educators, and hobbyists who want to explore the world of 3D modelling, circuit design, and even code-based projects. With Tinkercad, users can easily create 3D objects by manipulating basic shapes and exporting their designs for 3D printing. Additionally, the platform includes a feature for designing and simulating electronic circuits, enabling users to build and test circuits before physically assembling them. Tinkercad also supports block-based programming for microcontrollers like Arduino, allowing users to code and simulate their projects directly within the platform. Due to its simplicity, Tinkercad has become a popular tool in education and prototyping, making digital design and electronics more accessible to a broader audience.

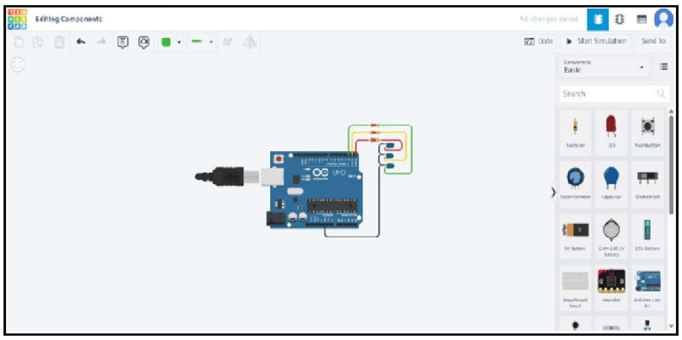

Fig. 6 TinkerCad Interface [17]

G. Arduino IDE

The Arduino IDE (Integrated Development Environment) is the software platform used to write, compile, and upload code (called "sketches") to Arduino boards. While the IDE itself is a software tool, its role in relation to a circuit diagram is crucial for understanding how the written code interacts with the physical components of an electronic circuit. The Arduino IDE allows users to write the instructions that control the electronic components depicted in a circuit diagram. For example, if your circuit diagram shows an LED connected to a specific digital pin on the Arduino, the IDE is where you write the code to turn that LED on or off, or to make it blink. Within the Arduino IDE, you define how the various pins on the Arduino board (which are connected to components in the circuit diagram) will function. You use functions like pinMode() to set a pin as an input or output, and digitalWrite() or analogWrite() to control the voltage on those pins, thereby controlling the connected components.

The IDE facilitates programming the Arduino to read signals from input components (like buttons or sensors) shown in the circuit diagram and to send signals to output components (like LEDs, motors, or displays) also present in the diagram.

Fig. 7 Arduino IDE Interface [18]

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III. METHODOLOGY

A. Objective

The main objective ofthis project is to design a system using Arduino Uno, Ultrasonic Sensor, Servo Motor, LCD Display, and Buzzer that can:

• Continuously detect the distance of nearby objects.
• Display the measured distance on an LCD screen.
• Trigger an alarm (buzzer) when an object is detected within a critical range.
• Use a servo motor to simulate motion or scanning behavior.

B. System Design

The system integrates both input and output components:

• Input: Ultrasonic sensor (HC-SR04) detects the distance to an object.
• Outputs:
o LCD Display (16x2): Shows real-time distance.
o Servo Motor: Continuously rotates or sweeps to simulate motion.
o Buzzer: Produces sound alert when an object is too close.

The Arduino Uno acts as the central control unit, processing input signals and controlling the output devices accordingly.

C. Working Principle

When the Arduino board is powered on, the servo motor begins sweeping from 0° to 180° repeatedly. The ultrasonic sensor continuously emits sound waves and listens for the echo reflected from any object. The time taken for the echo to return is measured and converted into distance using the formula:

$$\text{Distance (cm)} = \frac{\text{Time } (\mu\text{s}) \times 0.034}{2} \qquad (1)$$

The calculated distance is displayed on the LCD screen in real-time. If the distance falls below a predefined threshold (for example, 10 cm), the buzzer is activated as an alert signal. When no object is within that range, the buzzer remains off and the servo continues its motion.

D. Implementation Steps

• Circuit Assembly: Connect all components to the Arduino Uno according to the circuit diagram (sensor to D9 & D10, servo to D3, buzzer to D7, LCD via I2C to A4 & A5).
• Programming the Arduino: Upload the Arduino sketch that initializes all devices, reads sensor data, controls servo motion, updates the LCD, and activates the buzzer.
• Testing and Calibration: Test the system by placing objects at various distances and observing the LCD readings. Adjust the threshold distance or servo sweep speed in the code if needed.
• Final Operation: On successful calibration, the system runs automatically when powered. The servo moves, the ultrasonic sensor measures distance, the LCD displays it, and the buzzer sounds on close detection.

E. Block diagram and operation

The system block diagram (Fig. 8) and TinkerCad simulation setup (Fig. 9) represents the functional relationship between all the components used in the project — namely the Arduino Uno, Ultrasonic Sensor (HC-SR04), Servo Motor, LCD Display, and Buzzer.

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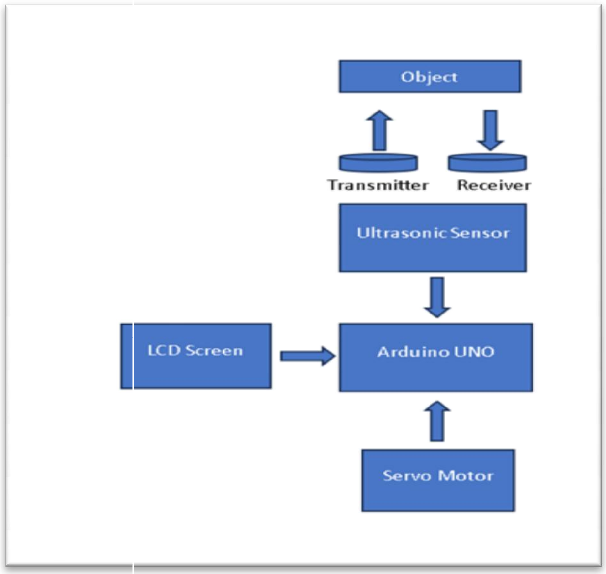

Fig. 8 System block diagram

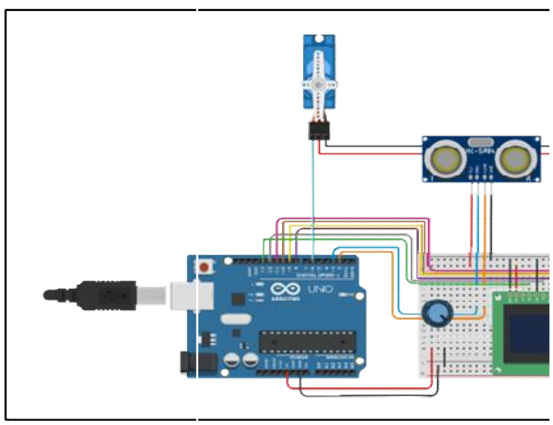

Fig. 9 TinkerCad diagram

The Arduino Uno acts as the central controller that receives data from the ultrasonic sensor and sends control signals to the servo motor, buzzer, and LCD display. Here's the functional breakdown of each block:

• Power Supply Block: The entire system is powered by the 5V DC output from the Arduino Uno, which can be supplied via USB or an external adapter. This power is distributed to all modules: ultrasonic sensor, servo motor, buzzer, and LCD display.

• Ultrasonic Sensor Block (HC-SR04): The ultrasonic sensor acts as the input sensing device. It sends an ultrasonic pulse through the TRIG pin and receives the reflected signal through the ECHO pin. The sensor measures the time delay between sending and receiving the sound wave and converts it into a distance value. This distance data is sent to the Arduino Uno for processing.

• Arduino Uno Block: This is the control unit or brain of the system. It performs the following tasks:

o Reads the input signal from the ultrasonic sensor.

o Calculates the distance using timing data.

o Controls the servo motor motion.

o Displays the distance on the LCD screen.

o Activates the buzzer if an object is detected within the threshold range (e.g., <10 cm).

All logic and decision-making operations are performed here based on the programmed code.

• Servo Motor Block: The servo motor is connected to a PWM pin of the Arduino. It performs rotational motion (usually sweeping between 0° and 180°) to simulate scanning movement or directional sensing. The Arduino sends PWM signals to control the servo angle.

• LCD Display Block (16x2): The LCD module displays the measured distance in centimeters. It also shows messages like "Object Detected" or "System Ready" based on the system's condition. If connected via an I2C interface, it uses the SDA (A4) and SCL (A5) pins for communication with the Arduino.

• Buzzer Block: The buzzer acts as an alert indicator. When the Arduino detects an object closer than the defined distance, it sends a HIGH signal to the buzzer pin, activating it to produce sound. When the object is far away, the buzzer is turned off.

• Signal flow summary:

o Power Supply → Arduino Uno → All Modules

o Ultrasonic Sensor → Arduino Uno: Distance data input.

o Arduino Uno → LCD Display: Distance value output.

o Arduino Uno → Buzzer: Alert output (sound).

o Arduino Uno → Servo Motor: Control signal for motion.

F. Result

The working of the physical implementation of the study Radar is shown in Fig. 10. The servo motor moves smoothly after power-up. The sensor detects distance. The Arduino reads the data and calculates the distance. The LCD displays the current distance. The LCD continuously shows accurate distance values. The buzzer activates when the distance is below the threshold, providing an audible alert. The system demonstrates the concept of distance measurement, motion control, and alert indication using simple embedded components. The servo motor keeps rotating, allowing scanning in different directions.

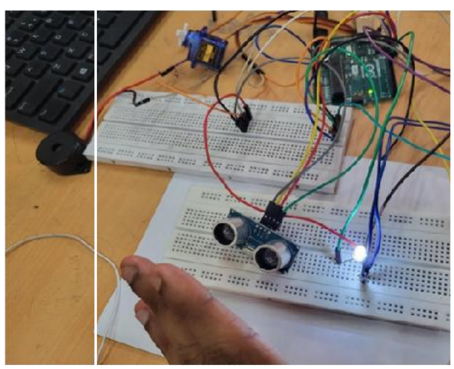

Fig. 10 Practical working model

IV. CONCLUSION

This study demonstrates how radar-based object detection can be a reliable alternative to vision-based systems, offering robustness in challenging conditions. It has significant potential for improving safety, automation, and security across various industries. Object detection using radar is a transformative project that leverages the unique capabilities of radar technology to overcome the limitations of traditional optical sensors. Through a comprehensive approach that combines hardware selection, advanced signal processing, machine learning-based classification, and rigorous testing, this project aims to deliver a reliable, real-time detection system suitable for a wide range of applications. The anticipated improvements in detection accuracy, robustness under adverse conditions, and real-time operational capability promise significant contributions to the fields of autonomous vehicles, surveillance, and industrial automation. As radar technology continues to evolve, its integration into multi-sensor systems will undoubtedly play a pivotal role in shaping

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the future of intelligent sensing and perception systems. By addressing the challenges and harnessing the strengths of radar, this project paves the way for more resilient and versatile object detection solutions that can adapt to a rapidly changing technological landscape.

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