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An IoT-Enabled Ultrasonic Radar Station for Real-Time Spatial Object Detection and Remote Monitoring

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Abstract: This paper designed and implementation based on the IOT Ultrasonic Radar Station, for which it is used distance measurement and object detection. Areas of use have been found within radar technology (radio detection and distance ranging). Various fields, including military installations and commercial sectors, where it measures physical properties such as distance, speed, position and size. The use of radar systems has been particularly significant in this regard in the field of navigation. This research explores the limitations of existing navigation technologies and is recommended a compact, cost-effective radar system built system the Nodemcu platform.The proposed system contains a basic ultrasonic sensor rider a servomotor, which rotates predefined angles and speeds. It is connected to both the ultrasonic sensor and the servo motor to the Nodemcu microcontroller's digital input/output pins. This activates setup the radar to scan its surroundings by excluding high frequency sound waves and detecting their reflections from nearby objects.The Arduino the distance and other reflected signals are processed. Existence of objects within its field of detection. The system provides a flexible system solution to other applications, including monitoring, navigation, and obstacle avoidance. This Nodemcu-based design lowers as compared to traditional radar systems, consumes power and is compatible with numerous open-source platforms.Being a mini-project, it shows an effective way of doing things using efficiency in the simplification of radar technology, and making it appropriate on small-scale applications like detection of objects and distance measurement.
Keywords: Ultrasonic radar, IoT, NodeMCU, Arduino Uno, HC-SR04, time-of-flight, object detection, radar visualization

I. INTRODUCTION

Each body generates pressure disturbances continuously as it occupies the air around it, and each disturbance manifests naturally. Many of these frequencies are above the limits of human hearing. Soundwaves above 20,000 Hz are considered ultrasonic and can be detected by specialized ultrasonic sensors to obtain useful information [8]. A high-pulses type ultrasonic detector uses transducers to switch between acoustic pulses and the electrical system [9]. This type of technology is applied for distance and orientation measurements, collision avoidance, monitoring [10]. Ultrasonic methods overcome linear measurement problems by facilitating the non-contact prediction of different ranges or speeds (and related amounts) [11].

In action, an ultrasonic sensor produces high-frequency pulses that pass in air and bounce off objects; the return echo can be used to measure an object's distance, direction, and motion [18]. Processing routines and Arduino code are used to calculate multiple object features while the sensors are assembled [13]. Wide range-detection is often called sonar, which is one of the applications of ultrasonic sensor [14].

Today's systems for sensing and detection are essential for automation, navigation, and security [15]. Traditional radar is based on radio-frequency electromagnetic waves for long-distance sensing however short-range and low-power needs can be satisfied by ultrasonic sensing devices [16]. A small, inexpensive system that simulates radar-like performance with sound allows easy construction and reliable performance in a teaching project or robotic platform, industrial automation when an in-field object detection is needed [17].

Ultra-radars are applications that use sound channels above 20 kHz to find objects in proximity by measuring the time from the transmitted pulses to their echoes [18]. These systems are echo-location-like, much like bats [19]. The sensor in such a station is attached to a servo that sweeps over a specific angular range, providing scanning capabilities of a semicircular or full circular sector [20]. During these pulses and reflections, the system calculates distances to obstacles and maps their position based on the orientation of the sensor [20].

A conventional ultrasonic radar station has several basic components. The ultrasound module (often HC-SR04) determines the range by measuring the gap between the transmitted pulse and the reflected echo [12]. A servo motor does angular sweeping and is analogous to traditional radar scanning [21]. A microcontroller is an instrument that organizes the sampling of sensors and control of motors through an Arduino [13]. It is able to transport information to a PC, display or display to host the sensing. A visualizer (that may be written in Processing or Python) generates real-time output in the shape of a radar-like circular chart to display objects detected in the form of a series of lines (blip or arc) [22].

Applications of ultrasonic radar stations are diverse. They enable obstacle avoidance and autonomous traversal in robotics applications and navigation autonomy [23]. In industry, they can sense things inside conveyor systems or the area of equipment to detect devices on conveyor systems and monitor controlled spaces in confined or restricted areas. They also provide educational content to students and hobbyists through sensors and visualization platforms, enabling learning of sensing, visualization, and embedded systems technologies [24].

The benefits include low power consumption, low cost, ease of assembly, and generalization from common parts, making them widely available for educational and practical use [25]. In this work, we intend to develop a practical ultrasonic radar station that will detect and map a live object for spatial detection using acoustic sensing. The system reproduces typical radar system performance on a smaller scale by capturing sound waves instead of electromagnetic radiation. Trial-based, hands-on learning of ultrasonic principles, servo actuation, data visualization, and live monitoring is possible. The app is a practical exercise in microcontroller coding, sensor communication, and graphical user interface, both in electronics and in computer science, to be gained by the students.

A. Radar Signal Detection Using Sound Waves

The radar-type signal detection with sound works in the same principle as the classical radar: to transmit such type of wave, the target must reflect it, and, therefore, reproduce an echo to obtain distance calculations [26]. This kind uses ultrasonic sound, which is greater than 20 kHz and is above the human sense in contrast to electromagnetic waves in the radio band [27]. It is also used in non-contact short range applications such as robot controlled collision detection, automobile parking assistance and automated industrial controls [29]. The systems are also referred to as ultrasonic radar as they are similar to the operation of the normal radar only that they are applied to transmit acoustic waves. Such a system has the two ultrasonic transducers in the centre where one transceiver generating high frequency pulses and the other one sensing the reflected echoes. Measurement of pulse round-trip time is done on a microcontroller (e.g. Arduino) and range obtained by time-of-flight computation [28].

To simulate the action of a sweeping radar, the ultrasonic sensor is commonly mounted on a servo motor with an angular range of action which is indicated to cause measurements to be taken on different bearings. The data is shown on a radar-like screen and the objects which are identified are shown as a blip in a circle plane. Although ultrasonic technology cannot be used in the long distance or high speed object compared to military or weather radars, it has advantages in terms of cost, simplicity, safety and easy combination. The systems work well in the controlled ambient conditions whereby there is need to possess the correct short range sensing and within an indoor setting. [30]

They are widely used in educational uses (robotics, educational instruction) and embedded system prototypes for illustrating the concepts of radar without the complexity of RF electronics. Practically, ultrasonic radar is also an effective and viable means of detecting real-time objects through acoustic frequencies in spite of constraints associated to conditions of the environment including temperature changes and surface characteristics [30].

II. RELATED WORK

In order to find objects with sound, in particular, with ultrasonic methods, the idea has been researched extensively in the past several decades, in a wide range of application areas, including robotics and traffic control, and embedded systems [18]. Though the electromagnetic radar is good in sensing over long distances, it is expensive and complex [16]. Ultrasonic sensors have been utilized in large scale by researchers and engineers as a cheap and quick substitute to meet needs of short range sensing [29]. Ultrasonic radar systems have a simplified system design that releases acoustic waveforms to detect obstacles and measure ranges. This technique is especially applicable to the short-range and real-time detection.

The application of HC-SR04 ultrasonic module on a servo motor to simulate robotics radar scanning has been proven previously [29]. Such systems can identify the location of obstacles inside a room at the range of about four meters with relative accuracy using an Arduino microcontroller, to control and visualize the information on the computer. In other studies, there are low-power ultrasonic radar prototypes which have been suggested to be used in smart vehicles and some of the capabilities to be incorporated in them have been highlighted as parking support and blind spot detection [31].

The responsiveness and reliability of ultrasonic sensing systems have also been enhanced by development of better signal processing techniques. Adaptive filtering influences have been investigated with the intention of rejecting environmental noise to enhance performance in detection on the target behavior under changing conditions [32]. The other being of research is to integrate ultrasonic radar with Internet of Things (IoT) platform where Wi-Fi enabled modules can be used to remotely monitor and transmit sensing data [33].

Although hampered by temperature sensitivity, low reflection of soft or sound-absorbing surfaces, ultrasonic radar is considered of interest because of its simplicity, low cost and usefulness in short range detection conditions [30]. Several laboratory systems have been made with ultrasonic modules to sense obstacles, distance, and radar type visualization of the surrounding environments.

Inexpensive Arduino-powered radar systems, which incorporate ultrasonic transmitter-receiver modules and servo motors, have been popularly used to emulate the simple workings of the conventional radar systems without using radio-frequency parts [34]. Models of the detection process in the ultrasonic sensing have been analyzed on the studies of the parameters such as distance, angular position and pulse timing [35]. Although the systems have higher computational complexity in shape recognition, this significantly broadens the application potentials of these systems in robotics and surveillance.

The other application in which ultrasonic ranging application has found extensive application is in the auto reversing systems. These systems also tend to contain error compensation features and dead-zone control and multimodal feedback (visual cues and auditory warnings) to make them safer [36]. Equally, there exist numerous Arduino based ultrasonic radar prototypes that exhibit utility in low power, low cost and facilitation of implementation in applications, such as object detection, security surveillance, and robotic navigation [37].

Others use angular scanning systems which offer as much as 180 degree view along with real time visualization on a computer to produce radar like space map of the objects detected [38]. In more sophisticated situations, especially where nondestructive testing is involved, noise may compromise weak echoes. Signal-processing methods including wavelet-based filtering have proven to have good results in enhancing noise-cutting and defect-detection [32].

Ultrasonic sensors of low cost can also be improved by the use of software based methods. Techniques used to interpolate ultrasonic distance measurements have been proved to enhance the accuracy of measurements proving that algorithmic enhancement may be used to supplement hardware development.

Other more modern versions have been developed of complete 360° environmental mapping with one rotating ultrasonic transceiver attached to a stepper motor [34]. These systems need strict motor control, calibration steps, optimization of the angular resolution and alignment with visualization software. IoT connectivity is frequently added, which enables the sensor data to be broadcast on networks to monitor it remotely and log data [33].

Angular and distance can be detected together by ultrasonic sensing systems, which are therefore especially important in situations where the vision-based systems can be ineffective in the low-light conditions or dusty conditions [39]. The geometry of the target and the angle of incidence are however key determinant factors of the performance of ultrasonic sensors. The experimental studies of the behavior of a ultrasonic sensor of various shapes and orientations have assisted in measuring the errors in measurements and refining calibration processes.

As more ultrasonic sensors are being used in vehicles and other products that involve security, security has also become an issue. Possibility of attack Researchers have undertaken work on possibility of attack whereby they inject malicious ultrasonic signals in an attempt to spoof sensor readings [40]. It has suggested the temporal and spatial pattern analysis of the sound signal dependent defensive mechanisms to differentiate natural echo, and malignant interference.

Other more modern methods like total variation regularization and other signal reconstruction methods have also been shown to have a higher signal to noises ratio than the more traditional filtering methods when tuned well [32].

Despite these technological successes there are still several limitations of ultrasonic sensing systems. These are limited operational range, surface reflectivity sensitivity, and incident angles sensitivity, environmental factors such as temperature and humidity affecting speed of sound and distance estimation [30]. Besides, this implies that scanning velocity in order to produce greater angular resolution can be compromised with detection accuracy and response time. Therefore, more active research work is yet to be conducted to focus on the improvement of the calibration techniques, the algorithm of filtering, the method of multi sensors fusion and the addition to the IoT and to its fine-tuning. From Table I, as can be seen, concerning ultrasonic radar systems, despite offering inexpensive and efficient short-range object detection, they are not devoid of their limitations; in fact, they are prone to the environment, as well as to limited sensing range and limited signal processing capabilities.

TABLE I: Comparative Analysis of Existing Ultrasonic Radar and Object Detection Systems

Reference	Year	Proposed Method / System	Hardware / Platform	Application Area	Key Contribution and Limitations
[29]	2018	Ultrasonic-based robotic sensing and navigation	Ultrasonic sensors, embedded controller	Robotics navigation	Demonstrated effective obstacle detection for mobile robots; limited sensing range and sensitivity to environmental noise
[31]	2020	Low-power ultrasonic radar system for vehicles	Ultrasonic transducer, microcontroller	Smart vehicle systems	Improved short-range sensing for parking and blind-spot detection; performance decreases in complex environments
[32]	2019	Adaptive filtering for ultrasonic signal processing	Signal processing algorithms	Industrial sensing	Enhanced echo detection in noisy environments; computational overhead increases with filtering complexity
[33]	2021	IoT-enabled ultrasonic radar monitoring system	Arduino, Wi-Fi module, ultrasonic sensor	Remote monitoring / IoT	Enabled remote data transmission and monitoring; depends on network reliability
[34]	2019	Arduino-based ultrasonic radar prototype	HC-SR04, Servo motor, Arduino	Educational / embedded systems	Low-cost radar simulation using acoustic sensing; limited scanning speed and detection distance
[35]	2020	Moving-object detection using ultrasonic radar	Ultrasonic sensors with signal analysis	Robotics monitoring	Introduced multi-parameter detection (distance, bearing, pulse timing); complexity increases with object recognition
[36]	2018	Ultrasonic-based automotive parking assistance	Ultrasonic sensors, embedded system	Automotive safety	Improved vehicle parking assistance with error compensation; limited accuracy for irregular objects
[37]	2019	Arduino-based ultrasonic radar detection system	Arduino, HC-SR04 sensor, servo motor	Security and robotics	Low power consumption and simple implementation; restricted to short-range object detection
[38]	2020	180° scanning ultrasonic radar with visualization	Arduino Uno, servo motor, PC visualization	Robotics and educational platforms	Real-time radar-like visualization of detected objects; limited angular resolution and sensing range
[39]	2020	Simultaneous angle and distance measurement system	Arduino and ultrasonic sensor	Embedded sensing systems	Effective for environments where vision-based systems fail; accuracy affected by object geometry
[40]	2021	Security framework for ultrasonic sensors in vehicles	Ultrasonic sensing systems with signal validation	Automotive cybersecurity	Introduced physical-layer protection against spoofing attacks; increased computational complexity

III. SYSTEM OVERVIEW AND ARCHITECTUR

A. Hardware Components

The suggested ultrasonic radar station with IoT is developed with the design of a two-controller architecture in order to scale sensing and communication activities apart so as to enhance reliability and scalability. The hardware modules of the system include the following:

1) Arduino Uno (ATMega328P): The main controlling unit that provides real time ultrasonic ranging; activating a servo motor, calculating time of flight and transferring data by serial. It operates at 5 V with a clock frequency of 16 MHz and provides digital I/O pins for sensor interfacing.
2) NodeMCU (ESP8266): Offers in-built Wi-Fi communication with the cloud. It obtains processed angle-distance information of the Arduino through UART and sends the structured data to an internet of things dashboard to monitor it. The ESP8266 operates at 3.3 V and supports TCP/IP protocol stacks.
3) HC-SR04 Ultrasonic Sensor: Application in non-contact distance measurement utilizing the time-of-flight (ToF) principle. The sensor works at a rate of around 40 kHz and provides distance measurements in the range of 2 cm to 400 cm under standard indoor conditions.
4) SG90 Micro Servo Motor: Allows angiography of the ultrasonic sensor. The servo turns over an adjustable distance of 0–180°, allowing spatial coverage of a semicircular region. The control of the servo is accomplished by PWM signals from the Arduino.

The sensing may be independently controlled through the modular hardware design, processing, and communication layers, and enhancing flexibility of the system and making debugging and expansion of the code easier.

B. Operational Workflow

The working model of the ultrasonic radar system is based on the following order of operation: data transmission process and cyclic scanning.

As a step, the servo motor is adjusted to move stepwise across the angular range that has been predetermined (typically 0° to 180°) with a configurable step resolution (e.g., 1°, or 2°). At each angular position, the Arduino generates a 10 µs trigger pulse to the ultrasonic sensor, initiating the emission of high-frequency sound waves.

As the emitted wave hits an object, then an echo of the reflected wave is sensed by the sensor's receiver. The Arduino is used to measure pulse period at the ECHO pin and calculates distance of time-of-flight equation:

$$d = \frac{t \cdot v}{2}$$

where $d$represents the measured distance, $t$is the round-trip echo time, and $v$is the speed of sound in air.

For each scan step, an angle–distance pair $(\theta, d)$is generated. These values are passed as serial communication (UART) to the NodeMCU module. The NodeMCU reads the data stream as it comes node by node basis, structures it in form of packets and uploads it to a cloud-based Wi-Fi platform.

Radar-style visualization of uploaded data is in real time, gauge meters, graphs or graphical dashboards. Such a continuous mechanism of scanning allows dynamic spatial mapping, and instant object recognition in the area being monitored.

The entire process is a combination of sensing, embedded processing, wireless transmission, and cloud visualization, making up a compact and software-defined networked surveillance system.

IV. MATHEMATICAL MODELING

A. Time-of-Flight Distance Estimation

The distance estimation through the proposed ultrasonic radar system is done using the time-of-flight (ToF) principle. On sending a sound ultrasonic pulse, the sound that is returned by an impedance appears with a time span which can be measured. The distance between the sensor is computed by using the round-trip travel time, and the object.

The basic Equation of ToF is as follows:

$$d = \frac{t \cdot v}{2}$$

where:

- d= distance to the object (m),
- t= measured round-trip echo time (s),
- v= speed of sound in air (m/s).

The factor $\frac{1}{2}$ accounts for the two-way propagation of the ultrasonic wave (sensor → object → sensor).
Under standard atmospheric conditions at $20°C$, the speed of sound is approximately:

$$v \approx 343 \text{ m/s}$$

The velocity of sound however, does not have a constant speed. A temperature-dependent approximation may be stated as follows:

$$v(T) = 331 + 0.6T \tag{4}$$

where T is the ambient temperature in degrees Celsius. Incorporating this compensation improves ranging accuracy in practical environments.

B. Distance Resolution

The smallest distance step that can be measured is related to the timing resolution of the microcontroller. If Δt represents the timer resolution, the theoretical distance resolution Δd is:

$$\Delta d = \frac{\Delta t \cdot v}{2} \tag{5}$$

In order to achieve timing resolution on the millimeter scale, the system can achieve this within microseconds accuracy of theory in an ideal case.

C. Angular Scanning Model

The servo motor rotates the ultrasonic sensor across a predefined angular range $\theta \in [0°, 180°]$ with step size $\Delta\theta$. For each angular position θ_i, a corresponding distance d_i is measured, forming discrete angle–distance pairs:

$$(\theta_i, d_i), i = 1,2, \dots, N \tag{6}$$

where

$$N = \frac{180°}{\Delta\theta}$$

D. Polar-to-Cartesian Transformation

Space is converted into the visualization and mapping of polar measurements, translated to Cartesian coordinates by using:

$$x_i = d_i \cos\theta_i \tag{7}$$

$$y_i = d_i \sin\theta_i \tag{8}$$

Such transformation makes it possible to plot in a radar style and locate objects in two-dimensional space.

E. Error Considerations

Measurement uncertainty arises from multiple sources, including:

- Variations in ambient temperature affecting sound velocity,
- Surface reflectivity and angle of incidence,
- Servo mechanical jitter,
- Timer quantization error.

The total distance error E_d may be approximated as:

$$E_d = E_t + E_v + E_m \tag{9}$$

where E_t is timing error, E_v is velocity-related error, and E_m represents mechanical and environmental disturbances.
The calibration of the systems is improved by the understanding of these aspects of modeling.

V. METHODOLOGY

The proposed ultrasonic radar is premised on an incremental multi-phase methodology: scanning, data acquisition, signal processing, cloud-based visualization, and serial communication.

A. Scanning and Data Acquisition

The scanning is realized with the help of the SG90 servo motor, operated by Pulse Width Modulation (PWM) signaling of the Arduino Uno. The servo has a set period of rotation, angular range of 0–180°. The angular resolution is configurable (e.g., 1° or 2°), thereby controlling spatial sampling density.

At each angular position θ_i, the Arduino initiates distance measurement by applying a 10 µs HIGH pulse to the TRIG pin of HC-SR04 ultrasonic sensor. This causes the release of an ultrasonic shot at around 40 kHz. On hitting an obstacle, the emitted wave is scattered; the sensor will receive the reflected echo as the sensor receiver.

The width of the pulse produced in the ECHO pin is proportional to the time-value of the round-trip travel of the acoustic wave. Internal timers are used in measuring this pulse duration at the Arduino. The measured time $t_i$is then converted to distance $d_i$via the time-of-flight equation:

$$d_i = \frac{t_i \cdot v}{2} \tag{10}$$

For each scanning step, an angle–distance pair $(\theta_i, d_i)$is generated. The generation is stored in memory and temporarily buffered. This will go on until the whole angular range has been scanned, building a discrete spatial map of the area under monitoring.

In order to enhance stability of measurements, optional averaging between repeated measurements of the echo reading per angle can be used. Also, it is possible to apply outlier filtering to suppress spurious reflections.

B. IoT Data Transmission and Cloud Integration

Having computed the angle–distance pair, the Arduino sends the data string with format through UART serial communication to the NodeMCU module. The communication has a predetermined baud rate (e.g., 9600 or 115200 bps).

The NodeMCU has the constant check of its serial input buffer. When a valid data packet is received by it, it does:

1) Parsing of angle and distance values
2) Data formatting into structured cloud fields
3) Wi-Fi transmission using TCP/IP protocols

To establish connection with, the ESP8266 Wi-Fi stack is made, an IoT cloud platform (e.g., ThingSpeak or others). Periodically, the angle and distance values are uploaded, enabling remote live visualization.

The values uploaded are presented in the cloud dashboard with the help of graphical elements like:

- Radar-style polar plots
- Gauge meters
- Time-series graphs

This architecture is capable of remote access through web browsers or mobile devices, real-time spatial monitoring, and recording the data for further analysis.

The entire methodology is a composite of embedded control, acoustic sensing, serial communication, and IoT networking, to obtain a small and scaled-down radar-inspired system.

VI. EXPERIMENTAL SETUP

The proposed ultrasonic radar that is equipped with IoT is experimentally validated. It was a controlled laboratory experiment run under indoor conditions. The installation is a combination of sensing, actuation, processing and wireless communication modules according to the following description.

A. Hardware Configuration

The Arduino Uno serves as the primary processing unit for servo control and ultrasonic ranging. The HC-SR04 ultrasonic sensor is connected as follows:

- VCC → 5 V
- GND → Ground
- TRIG → Digital Output Pin (e.g., D9)
- ECHO → Digital Input Pin (e.g., D10)

The SG90 servo motor is connected to a PWM-enabled digital pin (e.g., D6) for angular positioning control. A stable 5 V power supply is used to avoid voltage fluctuations during servo operation.

The NodeMCU (ESP8266) is interfaced with Arduino via UART serial communication:
- Arduino TX → NodeMCU RX (via voltage divider if required)
- Arduino RX ← NodeMCU TX
- Common Ground between Arduino and NodeMCU

Since the NodeMCU operates at 3.3 V, appropriate level shifting or voltage division is recommended to prevent damage.

B. Experimental Conditions
Experiments were conducted with:
- Scanning range: 0°–180°
- Angular step size: configurable (e.g., 1° or 2°)
- Measurement range: 2 cm to 400 cm
- Ambient temperature: approximately 20°C

Items of different sizes and surface characteristics were put in the detection area to measure system performance.

C. System Visualization
Figure 1 illustrates the complete circuit diagram of the proposed ultrasonic radar station. Figure 2 presents the physical experimental hardware arrangement used for data acquisition. Figure 3 shows representative radar-style visualization output generated from angle–distance measurements.

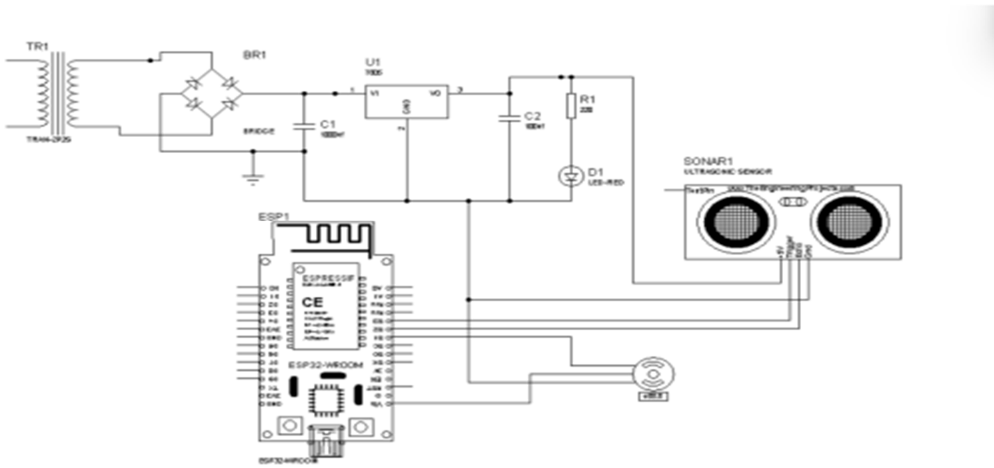

Fig. 1: Circuit diagram of the IoT-based ultrasonic radar station (Arduino Uno + NodeMCU + HC-SR04+ Servo)

Fig. 2: Experimental hardware setup with ultrasonic sensor mounted on servo for angular scanning.

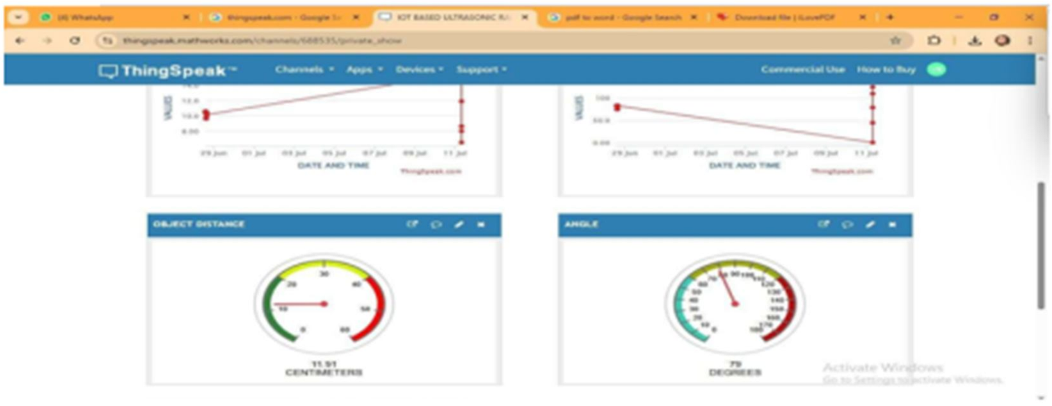

Fig. 3: Radar-style output visualization showing detected objects in polar coordinate representation.

VII. RESULTS AND DISCUSSION

The proposed ultrasonic radar system, as an IoT-enabled system, which was experimental, scanning tested in controlled conditions in the laboratory: accuracy, consistency in communication, and the ability to see it in real-time.

A. Scanning Performance

During operation, the servo motor successfully completed 0°–180° self-profiling sweeps with angular resolution. The Arduino was used to calculate the angular position of each angular position, measured with the time-of-flight principle and produced distance corresponding angle–distance pairs. The system reliably detected objects within the practical range of 2 cm to 400 cm, consistent with the HC-SR04 specifications. For static objects placed at known reference distances, the measured values showed close agreement with actual distances under indoor conditions (ambient temperature approximately 20°C).

B. Communication and IoT Performance

Communication between the Arduino and NodeMCU was consistent in serial. Since scanning is a continuous process, angle–distance data packets also at normal baud rates with no noticeable data loss were sent.

The data could be transferred to the established IoT cloud by the NodeMCU. It is a platform that is Wi-Fi powered. Remote dashboards were depicted; space can be monitored by means of real-time radar-like visualization via web and mobile media.In steady states of Wi-Fi, the latency in transmission was minimal to ensure that the system is suitable in real-time monitoring applications.

C. Measurement Accuracy and Limitations

Measured distances aligned well with expected values within the effective detection range (up to approximately 4 m). However, minor deviations were observed in the following scenarios:

- Near the mechanical limits of servo rotation, where slight positional jitter affected angular precision.
- On soft or acoustically absorptive surfaces, resulting in weaker echo reflections.
- At steep angles of incidence, where reflected waves did not return directly to the receiver.

These variations are consistent with known limitations of ultrasonic sensing systems.

D. System Effectiveness

Although the above limitations are possible, the proposed radar station is capable of being deployed and has shown performance satisfactory in the short-range object detection, remote monitoring applications, spatial awareness, and remote monitoring applications. The combination of embedded control with IoT connection was successfully able to provide real-time visualization and data logging.All in all, the findings prove that the system offers a scalable energy-efficient low-cost solution to robotics. The radar basics the radar father Mo scales Smoke and cockpit safety rules east-west indicators The Rolar scale System Hayden, N.d. smart monitoring environments, surveillance and surveillance.

VIII.CONCLUSION AND FUTURE WORK

This paper presented the design and implementation of a compact, low-cost IoT-enabled ultrasonic radar station for real-time spatial object detection and visualization. The proposed architecture integrates Arduino-based time-of-flight distance estimation with servo-controlled angular scanning to generate radar-like spatial mapping across a 180° field of view. It has wireless capabilities, which is provided by the addition of a NodeMCU (ESP8266) module, angle-distance conversion to a cloud-based transmission, like spatial mapping across a 180° field of view, and permitting external surveillance and real-time view.

Limited range detection was tested successfully in the experiment, in the effective working range of HC-SR04 sensor. The cloud synchronization and stable serial communication were verified. Efficiency of the two-controller system. The system provides an economical and energy saving system to control obstacle detection, robotic navigation, and many others: range surveillance, surveillance on a limited area, and radiographic illustration, the principles of radar.

The system is satisfactorily working in indoor short-range applications, some restrictions are present such as sensitivity to servo-induced angular jitter, environmental conditions and short range as compared to RF-based radar.

Future work may focus on:

- Integration of higher-precision ultrasonic transducers with improved range and beam directivity.
- Multi-sensor fusion techniques to achieve wider spatial coverage and enhanced object localization.
- Implementation of adaptive filtering or Kalman-based estimation to reduce measurement noise.
- Temperature compensation mechanisms for improved distance accuracy.
- Extension to 360° scanning using stepper motor actuation.
- Incorporation of machine learning models for motion prediction, object classification, and anomaly detection.

Such improvements can greatly increase system accuracy, resilience, and cognitive capabilities, which would allow it to be deployed in a greater number of places requiring real-world monitoring and independent sensing applications.

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