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Ultrasonic Sensor Based Motion Tracking Radar System for Smart Surveillance Applications

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***Abstract*— *The increasing demand for intelligent surveillance and automation systems has necessitated the development of efficient and cost-effective motion tracking solutions. This paper presents the design and implementation of a real-time Motion Tracking Radar System (MTRS) based on an ultrasonic sensing mechanism integrated with a servo-driven scanning unit and an ESP8266 microcontroller. The proposed system performs continuous environmental scanning by rotating the ultrasonic sensor across a predefined angular range and measuring object distances using the time-of-flight principle. Motion detection is achieved through temporal analysis of successive distance measurements, enabling accurate identification of dynamic objects. To enhance system reliability, signal processing techniques such as filtering, smoothing, and outlier rejection are incorporated to mitigate noise and measurement inconsistencies. The processed data is structured, stored, and visualized using a radar-like graphical interface, providing an intuitive representation of object position and movement. Furthermore, IoT-enabled wireless communication facilitates real-time data transmission to web-based platforms, allowing remote monitoring and analysis. Experimental evaluation demonstrates that the proposed system achieves reliable motion detection with acceptable accuracy in short-range and indoor environments while maintaining low cost, low power consumption, and implementation simplicity. Compared to conventional vision-based and infrared systems, the proposed approach offers a lightweight and scalable alternative with improved real-time performance and accessibility. The system is well-suited for applications in smart surveillance, obstacle detection, and automation. Future enhancements may include multi-sensor integration and intelligent data analytics to further improve system performance and adaptability.*

Keywords*— *Motion Tracking Radar System (MTRS), Ultrasonic Sensor, Real-Time Motion Detection, Internet of Things (IoT), Smart Surveillance, Servo Motor Scanning, Wireless Monitoring.

I. INTRODUCTION

The rapid evolution of intelligent systems, coupled with the widespread adoption of automation and Internet of Things (IoT) technologies, has significantly increased the demand for reliable motion detection and tracking solutions. These systems play a pivotal role in applications such as smart surveillance, autonomous robotics, industrial monitoring, and intelligent environments, where real-time awareness of dynamic surroundings is essential. Accurate motion tracking enhances system responsiveness, improves safety, and enables efficient decision-making in complex and time-sensitive scenarios. [1]

Conventional motion detection techniques, including vision-based systems and passive infrared (PIR) sensors, have been widely deployed in practical applications. However, these approaches suffer from several inherent limitations. Vision-based systems require high computational resources, are highly sensitive to illumination variations, and involve complex image processing algorithms, which increase system cost and latency. In contrast, PIR sensors provide only binary outputs and lack the ability to determine object distance, position, or movement trajectory. As a result, these traditional methods are often inadequate for applications requiring continuous tracking, spatial mapping, and real-time interaction [2]. To overcome these limitations, recent advancements in embedded systems and IoT technologies have enabled the development of compact, energy-efficient, and cost-effective motion tracking solutions. Ultrasonic sensing has emerged as a promising alternative due to its simplicity, affordability, and independence from lighting conditions. These sensors operate on the time-of-flight (ToF) principle, where emitted acoustic waves reflect from objects and return to the receiver, allowing distance estimation. When integrated with servo-based scanning mechanisms, ultrasonic sensors can provide spatial coverage by capturing distance data across multiple angular positions, thereby enabling a radar-like representation of the surrounding environment[3].

Despite these developments, a critical analysis of existing systems reveals several research challenges. Many low-cost implementations focus primarily on basic object detection and lack robust mechanisms for continuous scanning, accurate motion tracking, and noise-resilient data processing. Furthermore, limited attention has been given to integrating intuitive visualization techniques and real-time remote monitoring capabilities within a unified framework. The absence of efficient signal conditioning and post-processing methods often results in unreliable detection due to environmental noise, sensor inaccuracies, and interference. Therefore, there exists a significant research gap in designing a system that effectively combines affordability, real-time tracking accuracy, noise reduction, and IoT-enabled visualization in a single, scalable solution [4]. In response to these challenges, the present work proposes a microcontroller-based motion tracking radar system that integrates ultrasonic sensing, servo-actuated scanning, and wireless communication capabilities. The system is built around the ESP8266 microcontroller, which facilitates both data processing and IoT-based communication. By continuously rotating the ultrasonic sensor over a predefined angular range, the system acquires distance measurements at different orientations, enabling spatial mapping of the environment. Motion is detected by analyzing temporal variations in consecutive readings, allowing dynamic tracking of object movement [5].

To enhance system reliability and performance, fundamental signal processing techniques such as filtering, averaging, and outlier removal are incorporated to minimize the impact of noise and measurement errors. The processed data is transformed into polar coordinates and displayed through a radar-like graphical interface, providing an intuitive visualization of object position and movement patterns. Additionally, the integration of IoT connectivity enables real-time data transmission and remote monitoring through web-based platforms, improving accessibility and user interaction [5].

The primary contributions of this work can be summarized as follows. First, a low-cost and efficient motion tracking radar system is designed using readily available hardware components, ensuring ease of implementation and deployment. Second, the system enables real-time motion detection through continuous angular scanning and temporal data analysis. Third, the incorporation of signal processing techniques significantly improves detection accuracy and system robustness. Fourth, a radar-like visualization interface is developed to enhance interpretability of motion data. Finally, IoT-based wireless communication is integrated to support remote monitoring and real-time data access, making the system suitable for modern smart applications [5].

The proposed system addresses key limitations of existing approaches by providing a balanced solution that combines cost-effectiveness, accuracy, real-time performance, and connectivity. This makes it a viable and scalable option for applications such as security surveillance, obstacle detection, robotics, and smart automation systems.

II. LITERATURE SURVEY

The development of motion tracking and radar-based systems has gained significant attention in recent years due to the increasing demand for intelligent surveillance, automation, and smart monitoring solutions. Various approaches have been explored using ultrasonic sensors, embedded systems, and IoT technologies to achieve efficient object detection and tracking.

Ultrasonic sensing has been widely adopted for distance measurement and object detection due to its low cost and independence from lighting conditions. Recent studies have demonstrated the effectiveness of ultrasonic-based radar systems for real-time motion detection and environmental monitoring. Padamavathisrinidhi et al. [6] proposed an ultrasonic-based smart radar system integrated with IoT, highlighting its suitability for low-cost surveillance applications. Similarly, Hellas et al. and singh et al. [7], [8] developed a security radar system using ultrasonic sensors, emphasizing real-time detection capabilities in controlled environments. IoT-enabled monitoring systems have further enhanced the functionality of motion tracking applications by enabling remote data access and real-time communication. Verma and Jain [9] presented an IoT-based smart monitoring system that supports real-time data visualization and environmental tracking. Yadav et al. [5] also explored IoT-based alarm systems for smart city security, demonstrating the importance of wireless connectivity in modern surveillance systems. These studies highlight the growing trend of integrating sensing systems with IoT platforms to improve accessibility and system responsiveness.

Embedded system-based motion tracking solutions have also been extensively investigated. Patel et al. [10] developed a real-time motion tracking system using embedded sensors, demonstrating improved detection performance through efficient data processing. Similarly, Sajini et al. [11] proposed a proximity detection system combining ultrasonic sensing with IoT frameworks, showcasing enhanced reliability in real-world environments. Wang et al. [12] provided a comprehensive survey on ultrasonic sensing for indoor localization and tracking, emphasizing its effectiveness in short-range applications.

Signal processing techniques play a crucial role in improving the accuracy of sensor-based systems. Noise reduction and data filtering methods are essential for minimizing measurement errors caused by environmental disturbances. Huynh et al. and singh et al. [13], [14] demonstrated the use of ultrasonic sensing combined with smart automation techniques, highlighting the importance of preprocessing for reliable system performance. Jia et al. [15] further explored advanced ultrasonic-based spatial mapping techniques, indicating the potential for improved tracking accuracy through enhanced data processing methods. Visualization and system integration are also important aspects of modern radar systems. Lee and Kim [16] proposed embedded radar visualization techniques for object tracking, enabling intuitive graphical representation of spatial data. Additionally, Sharma et al. [17] introduced edge-enabled IoT architectures for real-time monitoring, emphasizing scalability and efficient data handling in distributed systems.

Despite these advancements, existing systems still face several limitations. Many low-cost implementations lack continuous scanning mechanisms, robust noise handling, and integrated visualization capabilities. Furthermore, the combination of real-time motion tracking, IoT communication, and efficient data management within a single system remains an open research challenge. These limitations highlight the need for a comprehensive solution that integrates sensing, processing, visualization, and communication in a unified framework.

Table 1. Comparison of Existing Motion Tracking Techniques

Ref. No.	Technique	Technology Used	Accuracy	Cost	Advantages	Limitations
[18]	Vision-Based Systems	Cameras, Image Processing	High	High	Rich information, object classification	Sensitive to lighting, high computation
[9]	PIR Sensors	Infrared Detection	Low–Moderate	Low	Simple, low power consumption	No distance/position info, binary output
[1], [12]	Ultrasonic-Based Systems	Ultrasonic Sensors	Moderate	Low	Cost-effective, lighting independent	Limited range, affected by noise
[15]	LiDAR-Based Systems	Laser Scanning	Very High	Very High	High precision, 3D mapping	Expensive, complex system

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[16]	RF/Radar Systems	Microwave/RF Signals	High	High	Works in harsh conditions	High cost, complex hardware
[17]	IoT-Based Monitoring Systems	Sensors and Wireless Modules	Moderate	Moderate	Remote monitoring, scalability	Depends on network reliability
[10]	Embedded Sensor Systems	Microcontroller and Sensors	Moderate	Low	Compact, efficient, real-time processing	Limited computational power
	Proposed MTRS	Ultrasonic and Servo and ESP8266	Moderate–High	Low	Real-time tracking, low cost, IoT-enabled, visualization	Limited range, indoor preference

The comparative analysis in Table 1 indicates that high-accuracy systems such as vision-based and LiDAR solutions are expensive and computationally intensive, while low-cost options like PIR sensors provide limited functionality. Ultrasonic-based systems offer a balanced trade-off between cost and performance but have range and noise limitations [6]. The proposed MTRS improves upon existing approaches by combining low-cost ultrasonic sensing with servo-based scanning and IoT integration, enabling real-time tracking, visualization, and remote monitoring while maintaining simplicity and affordability.

III. NEED OF MTRS (MOTION TRACKING RADAR SYSTEM)

The growing demand for intelligent monitoring and automation systems has made motion detection and tracking an essential component in modern technological applications. In environments where safety, security, and real-time decision-making are critical, the ability to continuously monitor surroundings and accurately detect object movement is indispensable. A Motion Tracking Radar System (MTRS) addresses these requirements by providing dynamic and continuous spatial awareness, which is not adequately achieved by conventional detection methods. One of the primary needs for MTRS arises from the limitations of traditional surveillance and sensing systems. Technologies such as CCTV cameras and passive infrared (PIR) sensors either require significant computational resources or provide limited detection capability without precise spatial information. These systems often fail to deliver accurate distance measurement, angular positioning, and real-time tracking, especially in resource-constrained or indoor environments. In contrast, an MTRS enables continuous scanning of the environment, allowing for precise localization and tracking of moving objects [10].

Another critical aspect driving the need for MTRS is the increasing importance of real-time monitoring in applications such as security systems, smart homes, and industrial automation. Continuous environmental scanning allows early detection of potential threats, obstacles, or unauthorized movements, thereby enhancing system responsiveness and reducing risks. This capability is particularly valuable in scenarios where immediate action or alerts are required, such as intrusion detection or collision avoidance in robotic systems.

The demand for cost-effective and energy-efficient solutions further highlights the significance of MTRS. Conventional radar systems are often expensive and complex, limiting their deployment in small-scale or low-budget applications. The use of embedded platforms, ultrasonic sensors, and servo mechanisms enables the development of affordable alternatives that maintain acceptable performance levels. Such systems are compact, lightweight, and easy to install, making them suitable for a wide range of practical applications without requiring extensive infrastructure. Additionally, the integration of MTRS with IoT technologies enhances its functionality by enabling wireless communication, remote monitoring, and data analysis. Real-time transmission of motion data to web or cloud-based platforms allows users to monitor environments from remote locations, improving accessibility and control. This feature is particularly beneficial in smart environments, where interconnected systems rely on continuous data exchange for efficient operation.

The MTRS also plays a significant role in improving the performance of autonomous and semi-autonomous systems. In robotics, for instance, motion tracking is essential for obstacle detection, navigation, and path planning. Accurate and continuous sensing of the surroundings allows systems to adapt dynamically to changes in the environment, thereby enhancing operational efficiency and reliability. The ability of MTRS to store and process motion-related data provides opportunities for advanced analytics and system optimization. Historical data can be used to identify movement patterns, predict behavior, and support intelligent decision-making processes [19]. This makes MTRS not only a monitoring tool but also a foundational component for developing smart and adaptive systems [10].

IV. METHODOLOGY

The proposed Motion Tracking Radar System (MTRS) is developed by integrating an ultrasonic sensor, servo motor, and ESP8266 microcontroller to achieve real-time object detection and tracking as block diagram shown in Fig.1. The ultrasonic sensor measures distance using the time-of-flight principle, while the servo motor rotates the sensor across a predefined angular range to perform environmental scanning [6]. The ESP8266 microcontroller controls the scanning process, collects distance data at different angles, and processes the readings in real time. Signal processing techniques such as filtering and outlier removal are applied to reduce noise and improve accuracy. Motion detection is performed by comparing consecutive distance measurements, where significant variations indicate the presence of moving objects.

The processed data is structured and stored in a database, then transmitted via Wi-Fi to a web-based interface for visualization in a radar-like format. Additionally, alert mechanisms are triggered when objects are detected within a critical range. The entire system operates in a continuous loop, enabling dynamic and real-time monitoring of the environment.

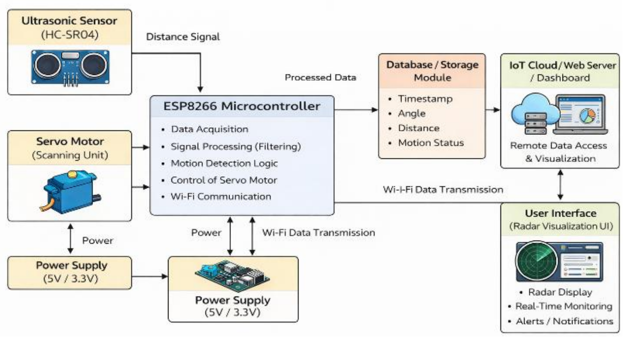

Fig.1. Block diagram of Ultrasonic Sensor Based Motion Tracking Radar System

V. REAL-TIME MOTION TRACKING AND DETECTION

The proposed Motion Tracking Radar System (MTRS) performs real-time detection and tracking of objects through coordinated sensing, scanning, and data processing. The system continuously monitors the environment using an ultrasonic sensor mounted on a servo motor, enabling angular scanning and dynamic object localization. The collected data is processed, analyzed, and transmitted for visualization and decision-making. Flowchart of the MTR system is shown in Fig.3.

5.1 Ultrasonic Sensing and Distance Measurement

The system utilizes an ultrasonic sensor to measure the distance between the sensor and surrounding objects. The sensor operates based on the time-of-flight (ToF) principle, where ultrasonic pulses are transmitted and the reflected echoes are received after striking an object. The time delay between transmission and reception is used to calculate the distance using the speed of sound. This method provides reliable distance estimation independent of lighting conditions, making it suitable for indoor and low-visibility environments. The sensor continuously generates distance readings, which serve as the primary input for motion detection [20].

5.2 Servo-Based Angular Scanning

To extend the sensing coverage, the ultrasonic sensor is mounted on a servo motor that rotates across a predefined angular range (typically 0° to 180°) as shown in Fig.2. The servo motor is controlled by the microcontroller to perform step-wise or continuous scanning. At each angular position, the sensor captures distance data, enabling the system to build a spatial representation of the environment. This scanning mechanism transforms the system into a radar-like configuration capable of detecting objects across multiple directions.

5.3 Signal Processing and Noise Reduction

Raw sensor data is often affected by noise due to environmental disturbances, surface irregularities, and sensor limitations. To ensure reliable detection, signal processing techniques are applied. Filtering methods such as moving average smoothing are used to stabilize fluctuating readings, while outlier detection mechanisms help eliminate abnormal values. These techniques improve measurement consistency and reduce false positives, thereby enhancing overall system accuracy.

Fig.2. ultrasonic radar system with sensor

5.4 Motion Detection Logic

Motion detection is performed by comparing consecutive distance measurements obtained during successive scan cycles. If the difference between current and previous readings exceeds a predefined threshold, the system identifies the presence of motion. This temporal comparison approach allows the system to distinguish between static and moving objects. Threshold-based logic ensures that minor fluctuations due to noise are ignored, while significant changes are classified as actual motion events [10].

5.5 Data Representation and Visualization

The processed data is mapped into a polar coordinate system, where each measurement corresponds to a specific angle and distance. This data is visualized in the form of a radar-like graphical interface. The visualization provides an intuitive representation of object position and movement patterns, allowing users to easily interpret real-time environmental changes. It enhances situational awareness and simplifies monitoring tasks.

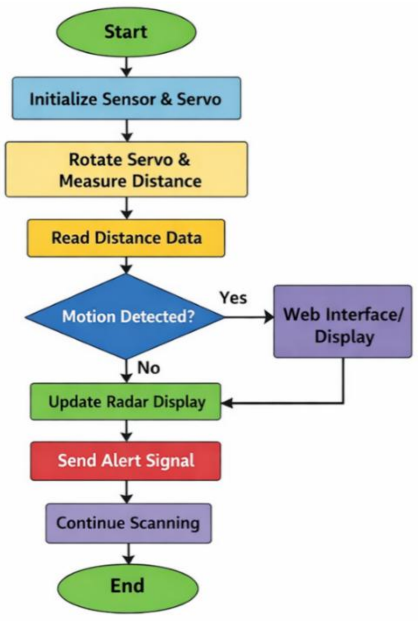

Fig.3. Flowchart of MTR system

5.6 IoT-Based Communication and Remote Monitoring

The system integrates the ESP8266 microcontroller, which enables wireless communication and IoT connectivity. The processed motion data is transmitted in real time to web-based or cloud platforms. This feature allows remote monitoring of the environment, making the system suitable for applications such as smart surveillance and automation [21]. Users can access live data, track object movement, and analyze system performance from remote locations.

5.7 Alert Generation and Response Mechanism

To improve system responsiveness, threshold-based alert mechanisms are incorporated. When an object is detected within a predefined critical distance, the system triggers alerts such as notifications or alarms. This functionality is particularly useful in security applications and obstacle detection systems, where immediate response is required to prevent potential hazards or unauthorized access [22].

5.8 Continuous Scanning and System Operation

The entire process of sensing, scanning, processing, and detection operates in a continuous loop. The servo motor repeatedly scans the environment, and the system updates object information in real time. This continuous operation ensures dynamic tracking of moving objects and maintains up-to-date environmental awareness. The system is designed to achieve a balance between accuracy, computational efficiency, and real-time performance.

VI. DATABASE MANAGEMENT

Efficient data management is a critical component of the proposed Motion Tracking Radar System (MTRS), as the system continuously generates real-time sensing data as shown in Fig.4 that must be stored, organized, and processed for analysis and visualization. The database module is designed to handle high-frequency data streams generated by the ultrasonic sensor during continuous scanning, ensuring reliable storage and retrieval without affecting system performance. The system captures multiple parameters at each scanning instance, including timestamp, angular position of the sensor, measured distance, and motion detection status. These parameters are structured into well-defined records and stored in a database to maintain consistency and enable efficient querying. The use of a structured data model ensures that redundancy is minimized while maintaining data integrity [6].

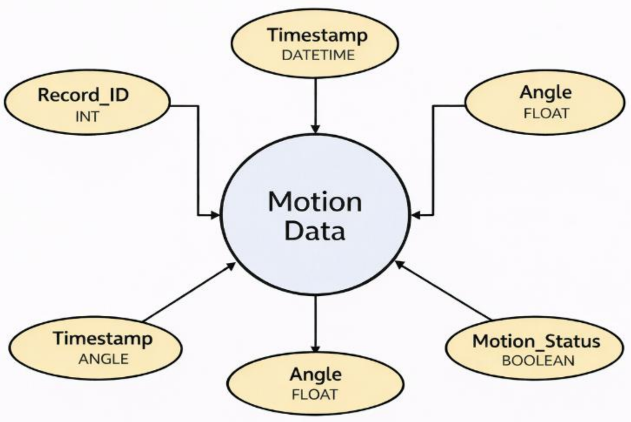

Fig.4. Motion Data

To support real-time operation, the database is optimized for fast write and read operations. As new sensor readings are acquired, they are immediately stored and updated in the database without introducing latency in the tracking process. This enables continuous synchronization between the sensing module and the visualization interface, ensuring that users receive up-to-date information. Data organization is achieved through the use of tabular structures, where each entry corresponds to a specific scan instance. Fields such as angle, distance, timestamp, and detection flag are systematically arranged, facilitating efficient indexing and retrieval. This structured approach allows for easy filtering, sorting, and analysis of motion tracking data. In addition to real-time storage, the system incorporates mechanisms for data validation and consistency checking. Erroneous or inconsistent readings resulting from sensor noise or environmental interference are identified and either corrected or discarded before being stored. This improves the overall reliability of the stored data and ensures accurate analysis. The database module is also integrated with IoT platforms and user interfaces, enabling seamless data synchronization between the local system and remote monitoring applications. This integration allows users to access live as well as historical data through web or mobile interfaces, enhancing system usability and accessibility [9].

To ensure data reliability and prevent loss, backup and recovery mechanisms are implemented. Periodic backups of the database are maintained either locally or on cloud storage platforms. The availability of historical data enables advanced analysis such as pattern recognition, behavior prediction, and performance evaluation. By analyzing stored motion data, the system can identify trends and support the development of intelligent decision-making algorithms in future extensions. Overall, the database management system plays a vital role in ensuring efficient handling of real-time motion data. Its structured design, real-time processing capability, and integration with IoT platforms make it a robust and scalable solution for modern motion tracking and monitoring applications.

VII. DATABASE MANAGEMENT FEATURES

The database management module of the proposed Motion Tracking Radar System (MTRS) incorporates several advanced features to ensure efficient handling, storage, and utilization of real-time motion data. These features are designed to support continuous operation, improve data reliability, and enable seamless integration with modern IoT-based monitoring systems [5], [9].

7.1 Real-Time Data Synchronization

The system supports real-time synchronization between the sensing unit and the database. As the ultrasonic sensor captures distance measurements during scanning, the data is immediately processed and stored without delay. This ensures that the database always reflects the latest environmental conditions, enabling accurate and up-to-date monitoring.

7.2 Integration with IoT Platforms

The database is seamlessly integrated with IoT communication frameworks through the ESP8266 microcontroller. This enables real-time transmission of data to web-based dashboards or cloud platforms. Users can remotely access live motion data, visualize object movement, and monitor system activity from any location [5], [9].

7.3 *Structured Data Organization*

All motion tracking data is stored in a well-defined structured format, ensuring consistency and ease of access. Parameters such as timestamp, angle, distance, and motion status are systematically organized, allowing efficient querying, indexing, and data retrieval for analysis and visualization.

7.4 *Data Reliability and Backup Mechanism*

To ensure data integrity and prevent loss, the system incorporates backup and recovery mechanisms. Data can be periodically stored in local or cloud-based storage systems. In the event of system failure, stored backups can be restored, ensuring continuity and reliability of motion tracking operations.

7.5 *Efficient Data Retrieval and Querying*

The database is optimized for fast retrieval of stored information. Users can access both real-time and historical data efficiently through filtering and querying mechanisms. This capability supports analysis of motion trends, detection patterns, and system performance evaluation.

7.6 *Scalability and Expandability*

The database architecture is designed to be scalable, allowing the system to handle increasing volumes of data without performance degradation. Additional parameters, sensors, or modules can be integrated without requiring major structural changes, making the system adaptable for future enhancements.

7.7 *Security and Access Control*

To protect sensitive data, the system incorporates basic security measures such as authentication and controlled access to the database. This ensures that only authorized users can view or modify system data, enhancing overall system reliability and trustworthiness.

7.8 *Support for Data Analytics and Visualization*

The stored data can be utilized for advanced analytics, including pattern recognition, anomaly detection, and predictive analysis. Integration with visualization tools enables graphical representation of motion data, such as radar displays and trend graphs, improving user understanding and decision-making [6].

VIII. INTEGRATION WITH OTHER SYSTEMS

The effectiveness of the proposed Motion Tracking Radar System (MTRS) is significantly enhanced through its ability to integrate with external systems and platforms. This integration enables extended functionality, improved accessibility, and seamless interaction with modern smart environments. By leveraging IoT technologies, communication interfaces, and cloud-based services, the system can operate as part of a larger intelligent ecosystem [13], [14].

8.1 *Integration with IoT Platforms*

The MTRS is integrated with IoT platforms using the ESP8266 microcontroller, which provides built-in Wi-Fi connectivity. This enables real-time transmission of motion tracking data to cloud servers or web-based applications. The integration facilitates remote monitoring, allowing users to access live sensor data and system status from any location. Additionally, IoT connectivity supports data synchronization across multiple devices, making the system suitable for distributed monitoring applications.

8.2 *Web and Mobile Interface Integration*

To enhance user interaction, the system is connected to web-based dashboards and mobile applications. These interfaces provide real-time visualization of object position and movement using radar-like displays, graphs, and alerts. Users can monitor environmental changes, review historical data, and configure system parameters through intuitive graphical interfaces. This integration improves usability and ensures that the system can be easily operated without requiring technical expertise [23].

8.3 *Integration with Smart Security Systems*

The MTRS can be integrated with smart security systems to enable automated responses to detected motion. When an object is identified within a predefined critical range, the system can trigger actions such as activating alarms, sending notifications, or initiating surveillance recording. This capability enhances security applications by providing proactive threat detection and immediate response mechanisms.

8.4 *Cloud Storage and Data Management Integration*

The system supports integration with cloud storage platforms for efficient data management and scalability. Motion tracking data can be stored securely in cloud databases, allowing long-term storage and easy retrieval. Cloud integration also enables advanced data processing, analytics, and sharing across multiple users or systems, thereby extending the functionality of the MTRS beyond local operation.

8.5 Integration with Automation and Control Systems

The MTRS can be interfaced with automation systems such as smart home devices and industrial control units. Based on motion detection, the system can initiate automated actions, such as switching lights, controlling appliances, or adjusting system parameters. This integration supports the development of intelligent and responsive environments that adapt dynamically to user activity and environmental conditions.

8.6 Alert and Notification Systems

Integration with notification services allows the system to send real-time alerts to users via mobile applications, emails, or messaging platforms. These alerts are generated when motion is detected within a critical range or when predefined conditions are met. This feature ensures timely awareness and enables quick response in safety-critical applications.

8.7 Interoperability with Embedded and Sensor Networks

The system is designed to be compatible with additional sensors and embedded modules, enabling multi-sensor integration. For example, it can be combined with temperature sensors, cameras, or gas detectors to create a comprehensive monitoring system. This interoperability enhances system capabilities and supports the development of advanced multi-parameter sensing applications [15].

IX. POST PROCESSING

Post-processing plays a crucial role in enhancing the accuracy, reliability, and usability of the data obtained from the Motion Tracking Radar System (MTRS). The raw data collected from the ultrasonic sensor is often affected by noise, environmental disturbances, and sensor limitations. Therefore, appropriate post-processing techniques are applied to refine the data before it is used for visualization, storage, or decision-making.

9.1 Noise Filtering and Data Smoothing

The initial stage of post-processing involves the removal of noise from raw sensor readings. Variations in measurements may arise due to acoustic interference, object surface irregularities, or environmental conditions. To mitigate these effects, filtering techniques such as moving average and smoothing algorithms are applied. These methods help stabilize the data by reducing fluctuations and ensuring consistent distance measurements. As a result, the reliability of motion detection is significantly improved, and false detections are minimized.

9.2 Motion Analysis and Change Detection

After filtering, the processed data is analyzed to identify motion within the scanning range. This is achieved by comparing consecutive distance measurements obtained during successive scan cycles. If the difference between readings exceeds a predefined threshold, the system interprets it as motion. This temporal analysis allows the system to distinguish between static objects and dynamic movement, enabling accurate tracking of moving targets.

9.3 Data Normalization

To maintain consistency across different scanning conditions, the collected data is normalized. Variations caused by sensor angle, environmental factors, or measurement inconsistencies are adjusted to ensure uniformity. Normalization ensures that the data remains comparable across different time intervals and scanning cycles, improving the robustness of the tracking system.

9.4 Outlier Detection and Removal

Sensor readings may occasionally contain abnormal or inconsistent values due to interference or hardware limitations. These outliers can negatively affect system performance if not handled properly. Outlier detection techniques are used to identify such irregular values based on predefined thresholds or statistical methods. Once identified, these values are either corrected or removed, ensuring that only valid data is considered for further processing.

9.5 Feature Extraction

Post-processing also involves extracting meaningful features from the refined data. Key parameters such as minimum distance, maximum detection range, object position, and movement patterns are derived. These features provide valuable insights into the environment and enable higher-level analysis, such as object tracking behavior and motion trends.

9.6 Data Formatting and Structuring

The processed data is converted into a structured format suitable for storage and transmission. Parameters such as timestamp, angle, distance, and detection status are organized systematically. This structured representation ensures compatibility with database systems, IoT platforms, and visualization tools, enabling efficient data handling and integration.

9.7 Visualization Preparation

Before presenting the data to users, it is transformed into a format suitable for graphical representation. The processed values are mapped into polar coordinates to create a radar-like display. Visualization elements such as arcs, points, and motion indicators are generated to represent object position and movement. This enhances interpretability and allows users to easily understand real-time environmental conditions.

9.8 Data Transmission for Remote Monitoring

Finally, the processed and structured data is prepared for transmission to external systems such as web interfaces or cloud platforms. Efficient encoding and communication protocols are used to ensure real-time data delivery with minimal latency. This enables remote monitoring, analysis, and decision-making, making the system suitable for modern IoT-based applications [5].

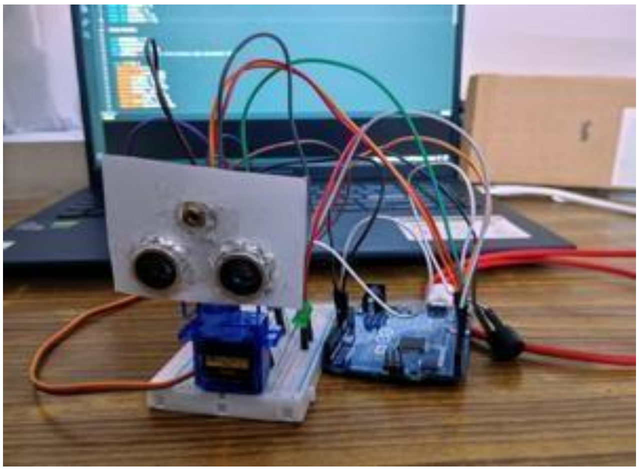

Fig.5. Final Hardware of MTR System

X. CONCLUSION

The proposed Motion Tracking Radar System (MTRS) presents an efficient and cost-effective solution for real-time object detection and tracking using embedded and IoT technologies as shown in Fig.5 . By integrating an ultrasonic sensor with a servo-based scanning mechanism, the system successfully captures spatial information of the surrounding environment and enables continuous monitoring. The use of the ESP8266 microcontroller facilitates both data processing and wireless communication, allowing seamless transmission of motion data to web-based interfaces for real-time visualization and remote access. The implementation demonstrates that reliable motion detection can be achieved through temporal analysis of distance measurements combined with basic signal processing techniques such as filtering and noise reduction. The radar-like visualization enhances user interpretability by providing an intuitive representation of object position and movement. Additionally, the incorporation of database management and IoT integration enables efficient data storage, retrieval, and remote monitoring, making the system adaptable to modern smart applications.

Experimental observations indicate that the system performs effectively within short-range environments, delivering acceptable accuracy and responsiveness for applications such as surveillance, obstacle detection, and automation. The overall design emphasizes simplicity, low power consumption, and ease of implementation, making it suitable for deployment in resource-constrained settings.

However, the system also has certain limitations, including restricted range, sensitivity to environmental conditions, and dependency on ultrasonic sensing accuracy. Future work can focus on enhancing system performance by incorporating advanced sensors, improving signal processing algorithms, and integrating machine learning techniques for intelligent decision-making and predictive analysis. Furthermore, expanding the system for multi-sensor fusion and large-scale deployment can significantly broaden its application scope.

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