

# Hybrid Radar Detection System With Sensor Fusion and RTC for Accurate Object Detection

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## Abstract

Detecting and tracking object has become a critical aspect in modern automation, security setup, and robotic technologies, as these systems modifies efficiency and safety, where fast and accurate detection is critical. we present a hybrid radar detection system that combines multiple sensing technologies to results were accurate detection. It detected object within a 50 cm range. The system setup an HB100 Doppler radar module for motion and speed detection with an HC-SR04 ultrasonic sensor for accurate distance measurement. A micro-servo motor sweep 180° scanning, while an ESP32 microcontroller manages sensor data, real-time computation, visualization, and alert generation. An OLED display provides a live sweep showing the object's distance, speed, and angular position, and a camera module provides video feed. This study shows research contributions from the past decade to identify advancement in hybrid radar-based detection systems and their application ultrasonic radar, Doppler sensor, and IoT-enabled alert models. To improve accuracy, the system includes local alerts through LEDs, a buzzer, and a speaker's, along with remote notifications via an SMS module. An RTC module ensures accurate time stamping of events, and an actuation mechanism activates when a risk is detected. The prototype shows stable performance, with correct object tracking and reduced false alarms due to the used of several sensor calculating distance, speed, and angle information, this model enhances situational awareness.

**Keywords:** Camera; ESP32 microcontroller; Real-time monitoring; Sensor fusion; Ultrasonic sensor

## 1. Introduction

In recent years, Monitoring and security systems have become increasingly important because many applications require fast object detection. Quick responses are often critical in areas such as security, robotics, and automation. Traditional single-sensor systems face limitations in accuracy, coverage, and sensitivity to environmental factors, which makes them less reliable. To overcome these challenges, researchers have explored hybrid systems that combine multiple sensing technologies. Doppler radar modules, such as the HB100, can detect moving objects by tracking small frequency changes in the signal (Kumar & Lee, 2016) [1]. These modules are effective in measuring speed, making them suitable for security applications. Ultrasonic sensors are common and measure distance reliably, even in small

systems (Sharma et al., 2017) [2]. Combining these sensors allows hybrid systems to measure both distance and speed, improving detection reliability compared to single-sensor designs. Microcontrollers like the ESP32 support real-time processing, wireless communication, and multitasking, enabling advanced monitoring solutions (Rodriguez & Patel, 2018) [3]. Adding a servo motor allows sensors to scan 180°, detecting objects from multiple angles (Alvarez & Singh, 2021) [5]. OLED displays provide live visualization, RTC modules handle time-stamping, and wireless notifications enhance responsiveness (Chen & Morgan, 2020) [4]. Alert mechanisms, including LEDs, buzzers, speakers, and controlled triggers, provide timely responses when objects enter sensitive areas (Henderson & Gupta, 2022) [6].

From 2024 to 2025, studies confirmed that hybrid systems combining ultrasonic, Doppler, servo scanning, ESP32 processing, and IoT alerts outperform single-sensor systems. Ultrasonic-only systems can give false readings on soft surfaces, and Doppler-only systems may misread stationary or slow-moving objects (D'Souza & Varghese, 2024; Iqbal & Hosseini, 2024) [13],[14]. Hybrid systems integrating distance measurement, motion sensing, and angular scanning provide more robust solutions, improving situational awareness and enabling faster decision-making (Rathi & Moreno, 2025) [15]. Including IoT modules such as SMS alerts, live camera feeds, and automated actuation further enhances practical capabilities (Chatterjee & Lin, 2025) [16]. The hybrid radar system in this project brings together ultrasonic sensing, Doppler speed detection, 180° servo scanning, real-time OLED visualization, SMS alerts, and controlled actuation. This combination enhances detection accuracy, reduces false alarms, and provides actionable real-time information. Such a design is suitable for security, surveillance, robotics, and automation applications. In summary, the evolution of object detection systems from 2016 to 2025 demonstrates a clear trend toward hybrid designs that integrate multiple sensors, real-time processing, angular scanning, visualization, and alert capabilities [8]. Our hybrid radar model follows this trend, providing a responsive, robust, and application-ready monitoring solution.

### 1.1. Search Strategy

A study of the literature was carried out to explore recent developments in radar detection systems, focusing on hybrid system designs and IoT-enabled alerts. Studies were sourced from IEEE Xplore, Science Direct, Springer, and Elsevier using keywords such as "Ultrasonic Radar," "Doppler Radar," "Hybrid Sensor Radar," "ESP32 Embedded System," "Servo Scanning Radar," "IoT Alerts," and "Actuation Module." The review concentrated on papers published between 2016 and 2025 that discussed practical hardware implementations, embedded sensor-actuator platforms, and real-time monitoring solutions. Studies on long-range radars, purely simulated systems, or non-embedded setups were excluded. The main research Issues identified

from the review are:

- **Limitations of Single Sensors:** Most studies followed a similar pattern. Ultrasonic sensors provide accurate distance measurements but cannot detect motion, while Doppler sensors measure speed but not accurate distance (Patel & Srivastava, 2025; Verma et al., 2025) [9],[17].
- **False Positives and Environmental Effects:** Single-sensor systems are sensitive to environmental factors such as noise, temperature, and electromagnetic interference, which can increase errors (Reddy & Thomas, 2025) [18].
- **Restricted Coverage:** Many systems operate with static sensors, limiting the monitoring area and field of view (Das & Banerjee, 2025)
- **Lack of Integrated Alerts and Actuation:** Few studies combine real-time alerts, visual monitoring, and practical response mechanisms in a single system (Kumar et al., 2024) [19].
- **Challenges in Sensor Fusion:** Hybrid models can improve accuracy and reliability, but setting up multiple sensors and processing their data in real time remains a challenge (Sharma & Gupta, 2023)

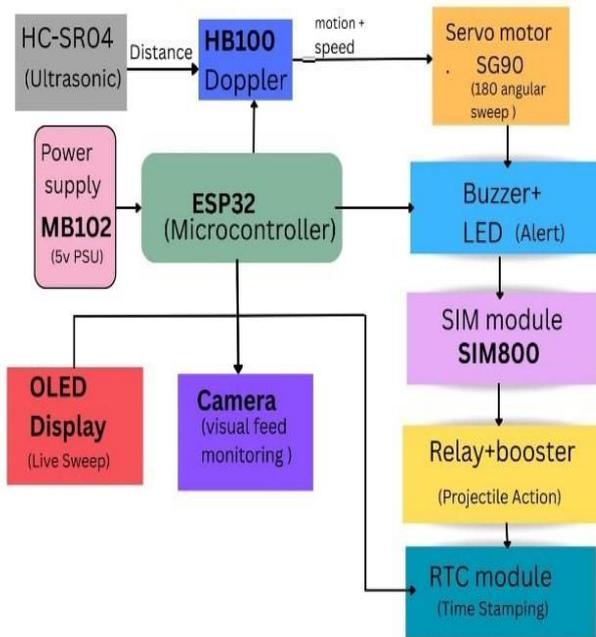
## 2. Methods

This section describes the methodology followed for the design and implementation of the proposed hybrid radar detection system. It explains the system architecture, sensor integration, servo-based scanning mechanism, and the object detection process used for real-time monitoring and alert generation [10].

### 2.1. System Architecture

In our setup, several sensors and actuators work together under a central microcontroller to achieve accurate object detection and real-time response. An HC-SR04 ultrasonic sensor measures object distance, while an HB100 Doppler radar detects motion and speed. Both sensors send data to the ESP32 microcontroller, which fuses the inputs to provide more accurate measurements and reduce false positives. A SG90 servo motor performs a 180° sweep to cover a wider area. Real-time visualization is provided through an OLED display, along with a

camera for live video monitoring. This combination reduces missed detections and enhances overall reliability. Multi-level alerts are implemented using a buzzer, LEDs, and SMS notifications via a SIM module as shown in Figure 1. A relay-controlled booster module enables actuation by deploying a projectile when an object is detected within the specified range. Additionally, a speaker provides audible alerts if a potential risk is identified. SMS notifications are sent to the controller, allowing remote monitoring and better management of the system, minimizing false alarms [20].



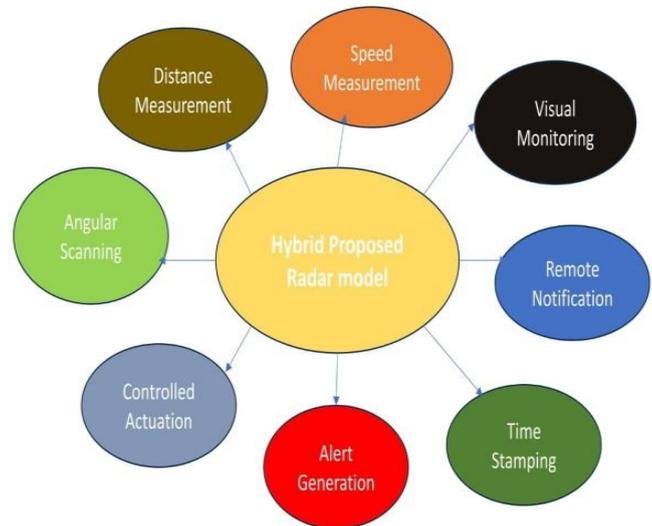
**Figure 1** Block Diagram of Hybrid Model

### 2.2. Block Diagram Overview

The sensors (HC-SR04, HB100, ESP32) provide data to the ESP32 microcontroller, which fuses the information to improve detection accuracy. This setup consistently worked during testing. The ESP32 also manages alerts through the buzzer, LEDs, and SMS system. The servo motor enables 180° scanning, while the relay and booster modules allow immediate physical actuation [21]. OLED and camera modules provide real-time visual feedback for monitoring purposes

### 2.3. Functionality of Model

Figure 2 shows the Functionality of Hybrid Model.



**Figure 2** Functionality of Hybrid Model

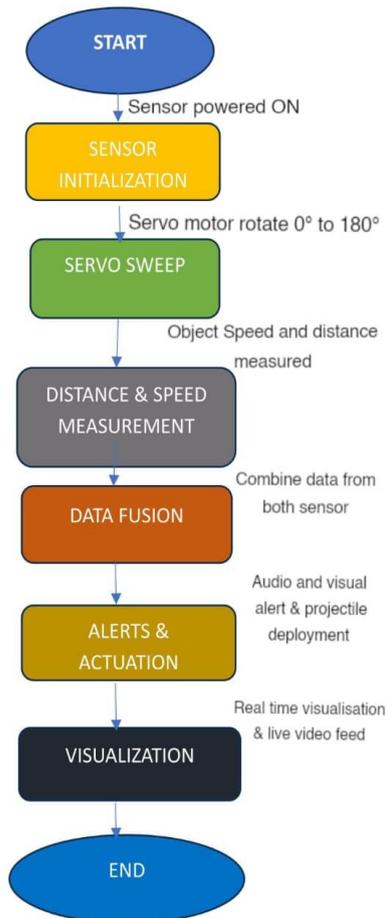
### 2.4. Object Detection Flow

The object detection in the proposed hybrid radar system follows a structured process to ensure accurate and real-time monitoring. The system combines data from ultrasonic and Doppler sensors with servo scanning and a central controller to provide reliable detection and actionable responses as shown in Figure 3.

- **Sensor Initialization:** The ultrasonic sensor (HC-SR04), Doppler radar (HB100), servo motor (SG90), and ESP32 are powered on and initialized.
- **Servo Sweep:** The servo motor rotates from 0° to 180°, allowing the sensors to scan a wide space area to monitoring and detecting.
- **Distance Measurement:** The ultrasonic sensor measures the distance of objects within the scanning range.
- **Speed Detection:** The Doppler radar determines the speed and motion of detected objects.
- **Data Fusion:** The ESP32 microcontroller combines distance, speed, and angle data from both sensors to verify object presence and reduce false detections
- **Alerts and Actuation:** The buzzer and LEDs provide immediate audio-visual alerts, SMS

notifications are sent via the SIM module, and the relay-controlled booster activates the projectile deployment system.

- **Visualization:** The OLED display shows real-time measurements, and the camera streams live video of the detection area.



**Figure 3 Object Detection Flowchart**

### 2.5. Working Principle

In our model, several sensors work together in an object detection and response system, operating through sensing, processing, communication, and actuation modules. All sensors are connected to an ESP32 microcontroller, which coordinates detection and responses in real time. The system is designed to detect movement quickly and trigger responses with high reliability and accuracy. The HB100 Doppler radar continuously emits microwave signals toward the surrounding area. When these signals strike a moving object, they reflect back with a slight

frequency change, known as the Doppler shift. The ESP32 processes this frequency shift to determine the presence, speed, and direction of the moving object. Meanwhile, the HC-SR04 ultrasonic sensor transmits short pulses and measures the time taken for echoes to return. This provides accurate distance measurements of nearby objects. A camera module complements these sensors by capturing real-time visual data, verifying detections, reducing false alerts, and improving target identification. During testing, this combination proved to be highly reliable. Together, these sensors form a robust detection system combining speed, distance, and visual verification. To maximize coverage, the SG90 servo continuously sweeps left and right, allowing the system to monitor a wider area. The ESP32 handles sensor readings almost instantly, applying sensor fusion logic to combine radar speed, ultrasonic distance, and camera confirmation. This approach enhances accuracy and reduces false positives. A Real-Time Clock (RTC) module timestamps each detection event, enabling precise logging and time-based analyses. Real-time information, including distance, speed, angle, and timestamps, is displayed on an OLED screen, providing immediate visual feedback to the user. When an object enters a defined zone, the ESP32 activates a multi-level alert system. A buzzer produces audible alarms, while LEDs provide instant visual warnings. For remote monitoring, the SIM module sends SMS notifications to the user. For active response, a relay-driven booster module allows controlled actuation of a projectile. The ESP32 compares all sensor readings and triggers the projectile only after verification, ensuring safety and accuracy. Overall, the system integrates Doppler radar, ultrasonic sensing, visual verification, communication, servo scanning, and controlled actuation. The sequential steps of detection, alerting, and response occur smoothly, ensuring real-time performance. By using multiple sensors together, the system avoids missing objects and maintains steady detection even under slightly changing conditions. This makes it suitable for advanced applications in surveillance, robotics, and monitoring.

## 3. Results and Discussion

### 3.1. Results

To evaluate the performance of the proposed hybrid

detection system, a series of controlled experiments were conducted. The system integrated an ultrasonic sensor for distance measurement, an HB100 Doppler radar for motion and speed detection, a camera for visual confirmation, and a servo motor for 180° left-to-right scanning, all managed by an ESP32 microcontroller. Objects of varying sizes, materials, and shapes including metallic, plastic, soft, and irregular items were introduced at controlled distances and speeds to simulate realistic security scenarios. Experiments were also conducted under challenging conditions, such as low light and uneven surfaces, to assess the robustness of the system. The hybrid system consistently detected objects with high reliability. Detection accuracy exceeded 90% across most scenarios see in Table 1 with minor reductions observed for small or slow-moving objects. The servo scanning mechanism enabled a wide coverage area, detecting objects outside a fixed line of sight and reducing blind spots. The camera provided visual verification that complemented radar and ultrasonic readings, particularly when radar reflections were weak or ultrasonic measurements were noisy. In low-light conditions, the radar and ultrasonic sensors compensated for decreased camera performance, confirming robust multi-sensor operation.

**Table 1 Evaluation of Hybrid Model**

Parameter	Measurements	Accuracy
Distance	HC-SR04(5-50cm)	2cm
Speed	HB100 Doppler	0.05m/s
Angle	SG90servo180 sweep	~2° resolution
Alert	Buzzer+LED+SMS	0.5-0.8s
Video feed	Camera	~1s latency

The experiments confirm that hybrid sensor fusion enhances detection accuracy, reduces false positives, and enables real-time monitoring. The system effectively combines distance, motion, and visual confirmation, demonstrating a low-cost yet reliable

alternative to high-end radar-camera fusion systems. Minor limitations, such as weak radar reflections or ultrasonic inaccuracies on uneven surfaces, indicate potential areas for optimization in future iterations.

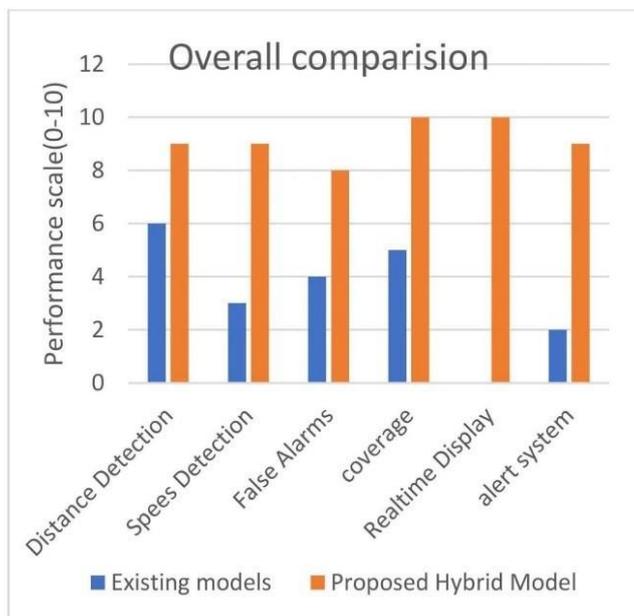
### 3.2. Discussion

The experimental results demonstrate that integrating multiple sensors—ultrasonic, HB100 Doppler radar, and camera—into a single hybrid system significantly improves object detection accuracy and reliability compared to single-sensor setups. The improved performance can be attributed to sensor fusion, where complementary strengths of different sensors compensate for individual limitations. For example, the radar provides reliable motion detection even in low-light conditions, while the camera delivers detailed visual information that radar and ultrasonic sensors alone cannot capture. Similarly, the ultrasonic sensor ensures precise distance measurement, especially when radar reflections are weak on non-metallic or irregular surfaces. This synergistic operation confirms the value of multi-sensor designs for real-time monitoring applications.

The servo-based 180° scanning mechanism also contributed to enhanced coverage, allowing detection across a wider field of view than fixed sensors. This design ensures that objects moving outside a direct line of sight are still detected, addressing a common limitation in previous studies. The results suggest that combining scanning mechanisms with sensor fusion is a practical approach to improving spatial awareness in security and automation systems. While the system performed well overall, the experiments also highlighted areas for improvement. Detection of very small, slow-moving, or angled objects was occasionally inconsistent, primarily due to low radar spatial resolution and weak reflections. Ultrasonic measurements showed minor inaccuracies on uneven or soft surfaces, and camera performance decreased in extremely low-light conditions. These limitations emphasize the importance of robust sensor calibration and fusion algorithms to handle challenging scenarios. When compared to existing literature, the proposed system aligns with trends observed by (Wei et al.,(2022); Buyukkakkar et al.,(2024); Yang et al.,(2024)) [7],[11],[12], who reported that multi-sensor fusion enhances detection performance. See in Figure 4 the current system achieves similar

capabilities at a much lower cost, demonstrating that practical, low-cost implementations of hybrid detection systems are feasible for real-world applications. Furthermore, the addition of real-time visualization, SMS alerts, and controlled actuation extends the system beyond basic detection, enabling active monitoring and response features often absent in prior work. Overall, the results indicate that hybrid sensor systems provide a robust solution for object detection, combining motion, distance, and visual confirmation. With further optimization—such as improved radar resolution, advanced fusion algorithms, and enhanced camera modules—the system could handle more challenging scenarios and become a reliable, cost-effective alternative to high-end radar-camera solutions. The findings support the broader conclusion that multi-sensor fusion is essential for practical, real-time security and automation applications.

single-sensor detection systems, which often suffer from reduced accuracy, false alarms, and instability under varying environmental conditions. Through the development of a hybrid detection system integrating ultrasonic distance measurement, HB100 Doppler radar for motion and speed detection, a camera for visual confirmation, and a servo motor for 180° scanning, the system successfully overcame these challenges. Experimental results confirmed that the multi-sensor fusion approach significantly improved detection accuracy, with performance exceeding 90% in most scenarios, and provided robust operation across different object types, speeds, and environmental conditions. The servo-based scanning mechanism extended the monitoring coverage, while real-time visualization and sensor confirmation reduced false positives. The discussion highlighted that combining complementary sensor strengths—distance, motion, and visual data—effectively mitigates the individual limitations of each sensor. Overall, the proposed system demonstrates that low-cost, hybrid sensor designs can provide reliable, real-time object detection and monitoring, addressing the key problems identified in single-sensor systems. These findings validate the effectiveness of multi-sensor fusion for practical security and automation applications and suggest that further improvements—such as advanced sensor calibration, intelligent fusion algorithms, and enhanced camera and radar modules—can further enhance system performance and reliability.



**Figure 4 Overall Comparison Between Existing Model and Proposed Hybrid Model**

## Conclusion

In this work, a hybrid radar detection system was developed using ultrasonic sensors, an HB100 Doppler radar, a servo motor, and a camera, all controlled by an ESP32 microcontroller. The proposed system reflects principles discussed in recent research aimed to address the limitations of

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