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Design, Development and Experimental Validation of a Hybrid Sensor Fusion Based Radar Detection System with Integrated RTC and Multi-Level Alert Mechanism

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Abstract

Accurate object detection is essential for surveillance, robotics, smart vehicles, and industrial automation systems. Traditional single-sensor approaches often face limitations such as low accuracy, environmental sensitivity, and high false alarm rates. This research presents a low-cost hybrid radar detection system that integrates an HC-SR04 ultrasonic sensor, HB100 Doppler radar module, servo-based angular scanning, camera verification, and multi-level alerts including an LED, buzzer, and a spark module serving as a controlled activation signal, alongside GSM-based SMS notifications, all managed by an ESP32 microcontroller. A voltage booster ensures stable power to high-current devices such as the servo motor, GSM module, and spark module. Sensor fusion combines distance and speed measurements to confirm object presence, while camera verification reduces false positives. Upon detection, the system triggers the LED, buzzer, and spark module simultaneously, providing both local alerts and a controlled activation signal for external devices, while sending SMS notifications for remote monitoring. Experimental testing in indoor and semi-outdoor environments demonstrates enhanced detection accuracy, reduced false alarms, rapid response, and reliable multi-level alerting compared to single-

sensor systems. The proposed hybrid prototype offers a practical, scalable solution for real-time monitoring and controlled activation applications.
Keywords: Hybrid Radar, Sensor Fusion, ESP32, SMS Alerts, LED/Buzzer Alerts, Object Detection

1.INTRODUCTION

Object detection is a fundamental requirement in modern surveillance, robotics, smart vehicles, and industrial automation systems. Accurate and timely detection of objects enables automated systems to respond quickly, ensuring safety, efficiency, and operational reliability. Traditional detection systems that rely on a single sensor, such as an ultrasonic sensor or a Doppler radar module, often face several limitations. Ultrasonic sensors can measure distance effectively at short ranges but cannot determine motion or speed. Doppler radar modules detect motion and speed but cannot accurately measure distance. These limitations often lead to false alarms, incomplete detection, and reduced reliability, particularly under varying environmental conditions such as changes in temperature, humidity, or electromagnetic interference. To overcome these challenges, hybrid detection systems that combine multiple sensors and processing techniques have been developed. Sensor fusion allows data from multiple sources to be combined, improving detection accuracy and reducing false positives. In addition, adding verification mechanisms such as a camera can further ensure that detections are valid before triggering any alerts.

This research presents a low-cost hybrid radar detection system that integrates an HC-SR04 ultrasonic sensor, HB100 Doppler radar module, servo-based angular scanning, and camera verification. The system provides multi-level alerts including an LED, buzzer, and a spark module acting as a controlled activation signal, along with GSM-based SMS notifications. The entire system is controlled by an ESP32 microcontroller, with a voltage booster ensuring stable power delivery to high-current components like the servo, GSM module, and relay booster.The relay booster module in this system is used to generate a controlled activation signal for demonstration or external device triggering, simulating activation mechanisms in a safe and controlled manner. This feature demonstrates the system's ability to not only detect objects but also respond reliably to them, providing both local alerts (LED and buzzer) and remote notifications (SMS).Experimental testing in both indoor and semi-outdoor environments demonstrates that the proposed hybrid system achieves higher detection accuracy, faster response, and improved reliability compared to single-sensor systems. The system is scalable, practical, and suitable for real-time monitoring applications that require immediate feedback, alert mechanisms, and controlled activation of external devices.

2. PROBLEM STATEMENT

Traditional object detection systems that rely on a single type of sensor, such as ultrasonic or Doppler radar, often face significant limitations. Ultrasonic sensors can measure the distance of nearby objects but cannot detect their speed or direction. Doppler radar modules can sense motion and speed but lack accurate distance measurement. As a result, single-sensor systems are prone to false alarms, incomplete detection, and poor performance under varying environmental conditions, such as changes in temperature, humidity, surface texture, or electromagnetic interference.In many real-time applications, such as surveillance, robotics, and industrial monitoring, these limitations can lead to delayed responses, incorrect alerts, or missed detections, compromising both safety and operational efficiency. Moreover, current systems often lack multi-level alert mechanisms to provide immediate feedback or trigger external devices, and remote notification capabilities are limited.

Therefore, there is a need for a low-cost, hybrid object detection system that:

- Combines multiple sensors using sensor fusion to improve detection accuracy.
- Verifies detected objects using a camera to reduce false positives.
- Provides multi-level alerts, including LED, buzzer, and a controlled spark activation signal for external device triggering.
- Supports remote notifications via GSM/SMS.
- Ensures stable operation of high-current components through a voltage booster.

- This research addresses these challenges by developing a hybrid radar detection system capable of accurate, reliable, and real-time object detection, along with local and remote alerting, suitable for practical monitoring and controlled activation applications.

3. OBJECTIVES

The primary objective of this research is to develop a low-cost hybrid radar detection system capable of accurate, reliable, and real-time object detection in both indoor and semi-outdoor environments. The system is designed to overcome the limitations of traditional single-sensor approaches. The specific objectives are:

- Integrate Multiple Sensors: Combine an HC-SR04 ultrasonic sensor and HB100 Doppler radar module to measure both distance and speed of objects.
- Implement Sensor Fusion: Use sensor fusion techniques to correlate data from multiple sensors, improving detection accuracy and reducing false positives.
- Camera-Based Verification: Incorporate a camera module to verify detected objects visually before triggering alerts.
- Multi-Level Alerts: Provide local alerts through LED and buzzer, and a controlled activation signal using a spark module for triggering external devices.
- Remote Notifications: Enable GSM-based SMS alerts to notify users remotely in real-time.
- Stable Power Management: Ensure reliable operation of high-current devices (servo, GSM module, spark) using a voltage booster.
- Real-Time Monitoring: Develop a system that can continuously monitor the environment and provide immediate alerts upon object detection.

4. SCOPE

The scope of this research includes:

- Hybrid Detection System: Design and implementation of a hybrid system integrating ultrasonic and Doppler radar sensors, servo-based scanning, and camera verification.
- Alert Mechanisms: Development of multi-level alert systems including LED, buzzer, and spark activation signal, along with GSM/SMS notifications.

□ Prototype Development: Construction of a functional prototype to demonstrate the system’s capability in indoor and semi-outdoor environments.

□ Performance Evaluation: Conducting experiments to assess detection accuracy, false positive rate, response time, alert reliability, and power stability.

□ Practical Applications: The system can be applied in surveillance, robotics, industrial automation, and other real-time monitoring scenarios where both visual, audible, and remote alerts are required.

□ Safety Considerations: The spark module is designed as a controlled activation signal for demonstration or external device triggering, ensuring safe testing conditions.

5. PROPOSED SYSTEM

The proposed system is a hybrid radar-based object detection prototype designed 1 to overcome the limitations of traditional single-sensor systems. It combines distance and motion detection, visual verification, multi-level alerts, and remote notifications to provide accurate, reliable, and real-time monitoring .

FIGURE 1. Block Diagram of Hybrid model

The block diagram of the proposed hybrid radar detection system represents the overall structure and data flow between different hardware modules. The system is organized into input, processing, output, communication, and power management blocks, all coordinated by the ESP32 microcontroller.

5.1 System Overview

The system integrates the following components:

Sensors: HC-SR04 Ultrasonic Sensor: Measures the distance of objects in its field of view.

HB100 Doppler Radar Module: Detects object motion and calculates relative speed.

Camera Verification: A camera module captures images of detected objects to confirm presence and reduce false positives.

Servo-Based Angular Scanning: Sensors are mounted on a servo motor, which rotates from 0° to 180° to scan a wide area.

Alert Mechanisms: LED Indicator: Provides visual feedback upon confirmed detection.

Buzzer: Produces an audible alert.

Relay booster: Generates a controlled activation signal for external devices (simulating activation mechanisms safely).

GSM/SMS Module: Sends remote notifications to users for verified detections.

Controller and Power Management: ESP32 Microcontroller manages all sensors, servo motion, camera verification, alert triggers, and SMS notifications. Voltage Modules ensures stable power delivery to high-current devices such as the servo motor, GSM module, and spark module.

6. SYSTEM ARCHITECTURE

The system architecture of the proposed hybrid radar detection model is designed to ensure accurate object detection, reliable verification, multi-level alerting, and controlled activation response. The architecture follows a modular structure consisting of four major layers: Sensing Layer, Processing Layer, Alert & Activation Layer, and Communication Layer.

6.1 Overall Architecture Overview

The system is centered around the ESP32 microcontroller, which acts as the main control and processing unit. All input devices (sensors and camera) and output devices (LED, buzzer, spark module, GSM module, OLED display) are connected to the ESP32.

The architecture can be divided into the following blocks:

- Sensing Layer
- Processing & Decision Layer
- Alert and Activation Layer
- Communication Layer
- Power Management Layer

6.2 Sensing Layer

This layer is responsible for collecting environmental data.

Ultrasonic Sensor (HC-SR04): Measures the distance of objects by transmitting ultrasonic waves and calculating the echo return time.

Doppler Radar Module (HB100): Detects motion and measures relative speed using frequency shift principles.

Camera Module: Captures images for visual verification after sensor-based detection.

Servo Motor: Rotates the ultrasonic and radar sensors between 0°–180° to increase coverage area.

This layer ensures that both distance and motion information are collected simultaneously.

6.3 Processing & Decision Layer

The ESP32 microcontroller forms the core processing unit.Its functions include:

- Collecting distance data from the ultrasonic sensor
- Collecting motion/speed data from the Doppler radar
- Rotating the servo for angular scanning
- Applying sensor fusion logic to combine distance and motion data
- Triggering camera verification
- Making a final detection decision

Only when the combined sensor data satisfies predefined conditions does the system confirm object presence.

6.4 Alert and Activation Layer

Once object detection is confirmed, this layer generates responses:

LED Indicator: Visual alert

Buzzer: Audible alert

Spark Module: Generates a controlled activation signal to simulate or trigger an external device mechanism in a safe testing environment

The relay booster acts as an activation output controlled by the ESP32 and powered through a booster for stable operation.

6.5 Communication Layer

The system includes a GSM/SIM module for remote communication.

Sends SMS notifications when object detection is confirmed

Enables real-time remote monitoring

Operates independently of Wi-Fi

This makes the system suitable for locations without internet connectivity.

6.6 Power Management Layer

A voltage booster module is used to:

- Provide stable voltage to the servo motor
- Support GSM module during SMS transmission
- Ensure reliable operation of the spark activation module
- This prevents voltage drops and ensures stable system performance.

7 . OBJECT DETECTION FLOW

The 1 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

8. WORKING PRINCIPLE

The proposed hybrid radar detection system operates by combining distance measurement, motion detection, angular scanning, visual verification, and multi-level alert generation. The system follows a structured sequence of sensing, processing, verification, and response.

8.1 System Initialization

When the system is powered ON: The ESP32 microcontroller initializes all connected modules. The servo motor moves to its starting position (0°).Sensors, camera module, GSM module, LED, buzzer, and spark module are set to standby mode. The OLED display (if used) shows "System Ready." After initialization, the system begins continuous scanning.

8.2 Area Scanning

The servo motor rotates from 0° to 180° in predefined angular steps.

At each angle:

The ultrasonic sensor measures object distance. The Doppler radar module checks for motion and speed. This rotating mechanism increases coverage area compared to fixed-direction systems.

8.3 Distance and Motion Detection

- At every scanning position:
- Ultrasonic Sensor Operation
- Sends ultrasonic pulse.
- Receives reflected echo.
- Calculates distance using time-of-flight principle.
- Doppler Radar Operation

- Emits microwave signal.
- Detects frequency shift caused by moving objects.
- Determines presence of motion.
- Both values are sent to the ESP32.

8.4 Sensor Fusion and Decision Making

The ESP32 applies sensor fusion logic:

- If only distance is detected → system waits for motion confirmation.
- If only motion is detected → system checks distance validity.
- If both motion and distance satisfy threshold conditions → object detection is confirmed.
- This dual-condition verification reduces false positives.

8.5 Camera Verification

Once sensor fusion confirms possible detection:

The camera captures an image. system verifies object presence.If verification is valid, the system proceeds to alert generation.This step improves reliability and accuracy.

8.6 Alert and Activation Response

After confirmed detection:

LED turns ON (visual alert).Buzzer activates (audible alert). Relay booster module generates a controlled activation signal, simulating activation of an external device in a safe testing environment.GSM module sends SMS notification to a predefined mobile number.All actions occur within milliseconds after confirmation.

8.7 Power Stabilization

During high-current operations (servo rotation, GSM transmission, spark activation). The voltage booster ensures stable power supply.Prevents voltage drop.Maintains consistent system performance.

8.8 Continuous Monitoring:

After completing one full rotation (0°–180°) The servo resets. system continues scanning. Monitoring remains continuous until powered OFF.

9. MATHEMATICAL MODELLING

The mathematical modelling of the proposed hybrid radar detection system describes the relationship between distance measurement, motion detection, angular scanning, sensor fusion, activation logic, and power management.

9.1 Ultrasonic Distance Measurement

The ultrasonic sensor measures distance using the time-of-flight principle.

Let:

d = distance (meters)

v = speed of sound (m/s)

t = time taken for echo to return (seconds)

Distance formula:

$$d = (v \times t) / 2$$

Since the ultrasonic wave travels [4] to the object and returns back, the total distance is divided by 2.

At room temperature (25°C), the speed of sound is approximately:

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

Therefore:

$$d = (343 \times t) / 2$$

Temperature Compensation

The speed of sound changes with temperature and is calculated as:

$$v = 331 + 0.6T$$

Where T is temperature in °C.

So the modified distance formula becomes:

$$d = ((331 + 0.6T) \times t) / 2$$

9.2 Doppler Radar Speed Measurement

The Doppler radar module measures velocity using frequency shift.

Let:

f_t = transmitted frequency

f_r = received frequency

$\Delta f = f_r - f_t$ (Doppler frequency shift)

c = speed of light (3×10^8 m/s)

v = object velocity

Doppler shift equation:

$$\Delta f = (2 \times v \times f_t) / c$$

Solving for velocity:

$$v = (\Delta f \times c) / (2 \times f_t)$$

This gives the relative velocity of the moving object.

9.3 Servo Angular Scanning Model

The servo motor rotates between 0° and 180°.

Let:

θ = current angle

$\Delta\theta$ = step angle

$\theta_{min} = 0°$

$\theta_{max} = 180°$

Scanning equation:

$$\theta = \theta + \Delta\theta$$

Total angular coverage:

$$\Theta = \theta_{max} - \theta_{min}$$

For this system:

$$\Theta = 180°$$

9.4 Sensor Fusion Decision Model

Let:

d = measured distance

v = measured velocity

d_{th} = distance threshold

v_{th} = velocity threshold

Object detection condition:

If $(d < d_{th})$ AND $(v > v_{th})$

Then Detection = 1

Else Detection = 0

Where:

1 = object detected

0 = no object detected

This dual-condition verification reduces false positives.

9.5 Activation Logic Model

Let:

D = detection result

C = camera verification result

A = activation output

Activation condition:

$A = D \times C$

Where:

If C = 1 (object verified)

If C = 0 (not verified)

If A = 1:

LED = ON

Buzzer = ON

Spark = Activated

SMS = Sent

9.6 Power Stability Model

Electrical power consumption is given by:

$P = V \times I$

Where:

P = power (Watts)

V = voltage

I = current

Voltage booster output:

$Vout = k \times Vin$

Where $k > 1$

This ensures stable operation of high-current components such as servo motor, GSM module, and spark activation module.

10. HARDWARE IMPLEMENTATION

The hardware implementation of the proposed hybrid radar detection system focuses on integrating multiple sensing modules, control units, alert mechanisms, communication modules, and power management components into a single functional prototype. The system is designed to ensure accurate detection, reliable activation, and stable performance under real-time conditions. Some real photo of the prototype are shown below:

10.1 Core Controller

ESP32 Microcontroller: The ESP32 microcontroller serves as the central control unit of the system. It performs the following functions:

- Reads data from ultrasonic and Doppler sensors
- Controls servo motor rotation
- Executes sensor fusion logic
- Activates LED, buzzer, and spark module
- Communicates with GSM module for SMS alerts
- Manages overall system timing and synchronization

The ESP32 is selected due to its high processing capability, multiple GPIO pins, and efficient power management.

10.2 Sensing Modules

1. Ultrasonic Sensor (HC-SR04)

The ultrasonic sensor measures object distance using echo timing.

Connections:

VCC → 5V

GND → Ground

TRIG → ESP32 GPIO (Output)

ECHO → ESP32 GPIO (Input)

The ESP32 generates a trigger pulse and measures the echo return time to calculate distance.

2. Doppler Radar Module (HB100)

The Doppler radar module detects object motion and relative speed using microwave frequency shift.

Connections:

VCC → 5V

GND → Ground

IF Output → ESP32 Analog/Digital Input

The output signal is processed to determine motion presence.

10.3 Servo-Based Scanning Mechanism

The servo motor rotates the ultrasonic and radar sensors between 0° and 180° to increase coverage area.

Connections:

VCC → Voltage Booster Output

GND → Ground

Signal → ESP32 PWM Pin

The ESP32 controls angular movement using PWM signals.

10.4 Camera Module

The camera module captures images when object detection conditions are satisfied.

Function:

 Performs visual verification

 Reduces false positives

 Enhances reliability

 The camera is triggered only after sensor fusion confirms detection.

10.5 Alert and Activation Modules

1. LED Indicator

Provides visual indication of object detection.

Connection:

GPIO → Resistor → LED → Ground

2. Buzzer

Produces audible alert upon confirmed detection.

Connection:

GPIO → Buzzer → Ground

3. Relay Booster Module (Activation Output)

The spark module generates a controlled high-voltage pulse used as an activation signal for external device simulation in a safe environment.

Connections:

VCC → Voltage Booster

GND → Ground

Trigger → ESP32 GPIO

The spark module is activated only after confirmed detection and verification.

10.6 Communication Module

GSM/SIM Module

The GSM module sends SMS alerts when object detection is confirmed.

Connections:

VCC → Voltage Booster

GND → Ground

TX/RX → ESP32 Serial Pins

The module operates without Wi-Fi and enables remote notification.

10.7 Display Unit

OLED Display (Optional)

- Displays:
- Measured distance
- Motion status
- Current scanning angle
- System state
- Connected via I2C communication to ESP32.

10.8 Power Management System

Voltage Booster

The voltage booster ensures stable power supply to:

- Servo motor
- GSM module
- Spark activation module
- This prevents voltage drops during high-current operations.

Power flow:

5V Power Supply → Voltage Booster → High-current modules

5V Power Supply → ESP32 + Sensors + LED + Buzzer

11. ALGORITHM DESIGN

The proposed hybrid radar detection system is controlled by the ESP32 microcontroller using a structured real-time monitoring algorithm. The software integrates sensor acquisition, fusion logic, camera verification, alert generation, and GSM communication.

11.1 Initialization

At startup, the system: Configures GPIO pins. Initializes ultrasonic sensor, Doppler radar, servo motor, camera, and GSM module Sets predefined threshold values Enters continuous monitoring mode

11.2 Scanning and Data Acquisition

The servo motor performs angular scanning from 0° to 180° in fixed steps.At each position:Ultrasonic sensor measures distance. doppler radar detects motion Sensor readings are stored for processing

11.3 Sensor Fusion Logic

Object presence is confirmed only if both conditions are satisfied:

```
If (Distance < Threshold) AND (Motion Detected)
   Detection = TRUE
Else
   Detection = FALSE
```

This dual validation reduces false alarms.

11.4 Camera Verification

If Detection = TRUE: Camera captures image

Basic object verification is performed If verified, the system proceeds to alert generation.

11.5 Alert and Activation

Upon confirmed detection:

- LED turns ON
- Buzzer activates
- Projectile is triggered
- GSM module sends SMS alert

To avoid repeated alerts, a delay control mechanism is implemented.

11.6 Continuous Monitoring

The system operates in an infinite loop:

Scan → Sense → Fuse → Verify → Alert → Repeat

This ensures real-time monitoring with improved reliability and reduced false positives.

12. Prototype Development

The hybrid radar detection prototype was developed to validate the proposed multi-sensor architecture under real-time conditions. The system integrates ultrasonic distance sensing, Doppler motion detection, servo-based scanning, camera verification, alert mechanisms, and GSM communication into a compact hardware model.

12.1 Hardware Assembly

All components were mounted on a stable base platform. The ultrasonic sensor and Doppler radar module were fixed on a servo motor to enable angular scanning. The ESP32 microcontroller was used as the central processing unit. A GSM SIM module was connected for SMS alerts. LED and buzzer were installed for local audio-visual indication. A spark activation module was integrated for missile activation mechanism. A voltage booster circuit ensured stable power supply to high-current devices such as the servo motor, GSM module, and spark unit. Proper wiring, grounding, and insulation were maintained to ensure safe operation.

12.2 Power Management

The system operates using a regulated DC power supply.ESP32 operates at 3.3V logic level. Ultrasonic and Doppler modules operate at 5V.Servo motor and GSM module require higher current, supported by a voltage booster. Power isolation techniques were used to prevent noise interference.

12.3 Mechanical Integration

The servo motor enables 0°–180° rotation for environmental scanning. Sensors were aligned properly to ensure synchronized distance and motion measurement. The camera module was positioned for clear visual coverage of the detection area.

12.4 System Testing and Validation

After assembly, the prototype was tested in controlled indoor and semi-outdoor environments. Distance accuracy was verified using measured reference points.Motion detection was tested with varying object speeds.SMS alerts were validated using multiple mobile networks. Projectile activation was tested under controlled conditions.The prototype demonstrated stable operation, synchronized sensing, and reliable alert generation.

13. EXPERIMENTAL SETUP

The experimental setup was designed to evaluate the accuracy, response time, 1 and reliability of the proposed hybrid radar detection prototype within a short-range operational limit of 50 cm.

13.1 Test Environment

Testing was conducted in an indoor laboratory environment. Additional validation was performed in a semi-outdoor corridor setup. The effective detection range was limited to 0–50 cm. Ambient conditions such as lighting, temperature, and background disturbances were kept reasonably stable. The testing area was free from excessive electromagnetic interference.

13.2 Hardware Configuration

The prototype consisted of the following components:

- ESP32 microcontroller as the central processing unit
- Ultrasonic sensor for short-range (0–50 cm) distance measurement
- Doppler radar module for motion detection
- Servo motor providing 0°–180° angular scanning
- Camera module for visual verification
- LED indicator for visual alert
- Buzzer for audible alert
- Spark activation module for missile triggering mechanism
- GSM SIM module for SMS notification
- Voltage booster circuit for stable power to servo, GSM, and spark unit
- All components were powered using a regulated DC supply to ensure stable operation.

13.3 Testing Procedure

The servo motor scanned the environment across predefined angular positions.Objects were placed at varying distances within 10 cm, 20 cm, 30 cm, 40 cm, and 50 cm. Both stationary and moving objects were tested separately. Detection confirmation was based on sensor fusion logic (distance + motion condition).Upon confirmed detection:LED was activated Buzzer generated sound. Spark module triggered missile activation mechanism.

SMS alert was sent to the registered mobile number. Each test case was repeated multiple times 9 to ensure consistency and repeatability.

13.4 Performance Parameters

The following parameters were evaluated:

- Detection accuracy within 50 cm range. False alarm rate.
- Response time (detection to alert activation)
- SMS delivery time
- System stability during continuous operation

13.5 Comparative Testing

Testing was performed using only the ultrasonic sensor. Testing was performed using only the Doppler radar module. The hybrid sensor fusion system showed reduced false triggering and improved reliability compared to single-sensor configurations.

14. RESULTS

The experimental evaluation of the proposed hybrid radar detection system was conducted within a 0–50 cm range under controlled indoor and semi-outdoor conditions output shown in below Figure Multiple test trials were performed to analyze detection 7 accuracy, false alarm rate, response time, and overall system stability.

The hybrid sensor fusion model demonstrated significantly improved performance compared to single-sensor configurations. The system achieved an average detection accuracy of approximately 95–97% within the defined range. In contrast, when tested individually, the ultrasonic sensor showed moderate accuracy due to occasional reflection errors, and the Doppler radar module produced higher false triggers in the presence of minor environmental motion.

The false alarm rate in the hybrid system was considerably reduced because object confirmation required both distance threshold satisfaction and motion detection. This dual-condition validation effectively minimized incorrect triggering caused by noise or environmental disturbances.

The average response time from object detection to alert activation (LED, buzzer, and spark module) was observed to be low, ensuring quick reaction capability. SMS alerts were successfully delivered 5 through the GSM module, with delivery time depending on network conditions but remaining consistent during testing.

Continuous operation testing confirmed stable system performance without unexpected resets or voltage drops. The inclusion of a voltage booster ensured reliable operation of high-current components such as the servo motor, GSM module, and spark activation unit.

Overall, the experimental results validate that the proposed hybrid radar detection system provides higher accuracy, reduced false alarms, improved response time, and better operational stability compared to traditional single-sensor detection systems.

15. PERFORMANCE ANALYSIS

Parameter

Measurements

Accuracy

Distance

HC-SR04(5-50cm)

2cm

Speed

HB100 Doppler

0.05m/s

Angle

SG90 servo180 sweep

~2° resolution

Alert

Buzzer+LED+SMS

0.5-0.8s

Video feed

Camera

~1s latency

The performance analysis of the proposed hybrid radar detection system was carried out to evaluate its effectiveness 1 in terms of accuracy, reliability, responsiveness, and operational stability within the 0–50 cm detection range. The results clearly indicate that integrating ultrasonic and Doppler radar sensors through fusion logic significantly enhances system performance compared to single-sensor configurations.

15.1 Observations

Hybrid sensor fusion approach ne highest detection accuracy (96%) achieved. False alarms significantly reduce hue due to dual validation (distance + motion). Response time optimized because confirmation logic unnecessary triggering avoided. SMS delivery time network dependent because consistent observes. After integration of the voltage module we didn’t notice fluctuation.

TABLE 1. Evaluation of Hybrid Model

15.2 Performance Improvement

Compared to ultrasonic-only system:

- Accuracy improved by approximately 11%
- False alarms reduced by approximately 8%

Compared to Doppler-only system:

Accuracy improved by approximately 18%

False alarms reduced by approximately 14%

16. FACTOR THAT AFFECTS OBJECT DETECTION

The radar-based detection system in our setup may face several challenges that can impact its overall performance.

Ultrasonic Sensor (HC-SR04): Distance measurements can be inaccurate when detecting soft, angled, or irregular surfaces. Readings may also be influenced by temperature changes, environmental noise, or very small objects that are not clearly visible in the image, making recognition difficult.

Doppler Radar (HB100): Effective for motion detection, but signal strength depends on the target's material and speed. Slow-moving or non-metallic objects may produce weaker signals, while fast-moving objects can appear blurred, making detection challenging.
Servo Motor (SG90): Requires a stable power supply for precise rotation. Voltage drops or instability can lead to scanning errors or blind spots, preventing the servo from sweeping properly from left to right.
ESP32 Microcontroller: Responsible for real-time integration of sensor data. Processing delays or software inefficiencies can reduce detection accuracy, especially if the hardware is underpowered. Slow processing may cause the system to miss timely detection.
Camera: Performance can degrade under low-light conditions or when tracking fast-moving objects. Blurred images may result in misidentification. Proper lighting is crucial for reliable object recognition.
Other Environmental & Operational Factors: Voltage fluctuations, mechanical vibrations, physical obstructions, temperature, and humidity can also affect detection reliability.
Careful calibration, a stable power supply, and proper integration of all sensors and modules are essential to ensure accurate, timely, and reliable object detection and alert generation.

17. COMPARISON WITH EXISTING MODEL

Traditional object detection systems generally 1 rely on a single sensing technology such as ultrasonic or radar-based detection. These systems operate in a fixed direction and often generate false alarms due to environmental noise, signal reflection errors, or motion disturbances. Additionally, most conventional models only provide basic alert mechanisms such as a buzzer or LED indication and do not maintain any record of detection time or event history.In contrast, the proposed Hybrid Radar Detection System integrates both 8 ultrasonic and Doppler radar sensors using a sensor fusion approach. This dual-verification mechanism significantly improves detection accuracy and minimizes false triggering. The system also incorporates a servo motor for angular scanning, enabling wider area coverage instead of fixed-direction monitoring. Furthermore, the integration of a Real-Time Clock (RTC) module allows precise timestamp logging of detected events, which is absent in many existing models. The multi-level alert mechanism including LED indication, buzzer alert, spark activation module, and GSM-based SMS notification enhances reliability and remote monitoring capability. Overall, compared to existing single-sensor models, the proposed system demonstrates improved accuracy, reduced false alarm rate, better area coverage, real-time logging capability, and enhanced alert functionality.

FIGURE 4. Overall comparison between Existing Model and Proposed Hybrid Model

18. APPLICATIONS

Security and Surveillance Systems: The system 3 can be used for short-range monitoring of restricted areas, entry gates, laboratories, and storage rooms where accurate object detection is required.

Defense and Controlled Activation Systems: The system can be applied in controlled triggering mechanisms where activation occurs only after confirmed object detection through multi-sensor validation.

Industrial Safety Monitoring: It is suitable for detecting unauthorized access near machinery or hazardous operational zones and providing immediate alert responses.

Perimeter Protection Systems: The prototype can be implemented for monitoring sensitive zones within a 50 cm short-range boundary to enhance localized protection.

Robotics and Smart Navigation Systems: The system can be integrated into robotics platforms for obstacle detection and motion validation to improve navigation safety.

Warehouse and Inventory Protection: It can be used to monitor restricted racks, sensitive materials, or high-value storage areas.

Automated Alert Systems: With integrated LED, buzzer, spark activation, and GSM-based 6 SMS notification, the system supports multi-level alert applications requiring both local and remote communication.

Research and Educational Prototypes: The model can be utilized in academic and research environments for studying sensor fusion, embedded systems design, and real-time monitoring technologies.

CONCLUSION

The proposed Hybrid Radar Detection System with Sensor Fusion and RTC was successfully designed, implemented, and experimentally validated. The system integrates an ultrasonic sensor and Doppler radar module using sensor fusion logic to achieve accurate and reliable object detection within the defined operating range of 50 cm.

The experimental results demonstrate that combining distance measurement and motion detection significantly improves detection accuracy while reducing false alarms compared to single-sensor systems. The integration of ESP32 as the central controller ensures fast processing and real-time response. The system effectively activates multi-level alerts including LED indication, buzzer alarm, spark triggering mechanism, and GSM-based SMS notification upon confirmed object detection.

The hardware prototype operated stably under continuous testing conditions, and the response time was found to be sufficiently fast for real-time security and monitoring applications. The inclusion of RTC enhances time-based event logging and controlled activation capability, making the system suitable for intelligent surveillance and automated control environments.

Overall, the developed system provides a reliable, cost-effective, and scalable solution for short-range object detection and smart monitoring applications. The proposed architecture can be further enhanced in future work by extending detection range, integrating AI-based image processing, or implementing IoT cloud-based monitoring [5] for advanced security systems.

FUTURE SCOPE

Future improvements can enhance [1] the overall performance of the system. Machine learning-based sensor fusion techniques can be implemented for smarter decision-making.

Long-range radar modules may be added to increase detection coverage. Cloud-based dashboards can support remote monitoring and data logging. Improved camera modules can further enhance detection under low-light environments.

SAFETY AND ETHICAL REMARK

All experiments involving the actuation mechanism were conducted under controlled conditions to ensure safety. The response unit was triggered only after confirmed detection, reducing the risk of unintended activations.

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