

Object Movement Detection System Using GPS, Passive Infrared Sensor, and Ultrasonic Sensor for Military Training Applications

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Abstract: *Area security and movement control play a critical role in military training operations, particularly in tactical exercises conducted within restricted and predefined zones. Effective detection and monitoring of troop movement are required to ensure training safety, operational realism, and accurate situational awareness. Inadequate or delayed detection may lead to training disruption, reduced effectiveness, and potential safety risks. This paper proposes an integrated object movement detection system based on a microcontroller platform Arduino Nano and ESP32, utilizing a Passive Infrared (PIR) sensor, an ultrasonic sensor, and a Global Positioning System (GPS) module to implement a multi-level early warning mechanism for military training applications. The PIR sensor is employed to detect human motion through infrared radiation changes, while the ultrasonic sensor measures object distance using ultrasonic wave propagation to identify critical proximity thresholds. The GPS module enables real-time tracking of troop positions, with collected data transmitted wirelessly to a centralized monitoring server for remote supervision. The proposed system generates staged alerts, including an initial warning upon movement detection and a secondary warning when the object enters a predefined critical zone, delivered via audio indicators and telemetry-based notifications. Experimental evaluation conducted under simulated training scenarios demonstrates that the system is capable of accurately detecting movement, providing reliable distance measurement, and supporting real-time location monitoring with acceptable response time and stability. The results indicate that the proposed system enhances training safety and control, offering a modular and scalable solution suitable for the development of advanced sensor-based early warning and monitoring systems in military training environments.*

Keywords: *Early Warning System, Military Training, PIR Sensor, Ultrasonic Sensor, GPS, Microcontroller Arduino Nano and ESP32, Object Movement Detection*

Introduction

Military training activities, particularly tactical and field exercises, require a high level of control, safety, and situational awareness to ensure that training objectives are achieved without compromising personnel security. Training scenarios often involve predefined restricted zones, simulated targets, and controlled movement paths where troop mobility must be closely monitored. Failure to detect movement accurately or to provide timely warnings can result in ineffective simulations, increased operational risk, and potential safety hazards for training participants. Therefore, the implementation of a reliable movement detection and monitoring system is essential to support safe and effective military training operations.

Recent advancements in embedded systems and sensor technologies have enabled the development of automated detection systems that operate in real time and can be deployed in various security and monitoring applications. Sensors such as Passive Infrared (PIR), ultrasonic sensors, and Global Positioning System (GPS) modules are widely used due to their low power consumption, cost efficiency, and compatibility with microcontroller-based platforms Arduino Nano and ESP32. PIR sensors are capable of detecting human

motion based on changes in infrared radiation emitted by the human body, making them suitable for initial motion detection. Ultrasonic sensors, on the other hand, provide precise distance measurements by analyzing the time-of-flight of ultrasonic waves, allowing accurate determination of object proximity. GPS technology further complements these sensors by enabling real-time location tracking of personnel during training activities.

However, systems that rely on a single type of sensor often suffer from limitations related to environmental conditions, detection range, or measurement accuracy. For example, PIR sensors may be affected by ambient temperature variations, while ultrasonic sensors can experience signal degradation due to surface characteristics or environmental noise. To overcome these limitations, sensor fusion approaches that integrate multiple sensing modalities have been widely adopted to improve system reliability and detection accuracy. By combining motion detection, distance measurement, and position tracking, a multi-sensor system can provide more comprehensive and robust situational awareness.

In the context of military training, movement detection systems serve not only as security

tools but also as tactical simulation instruments designed to train personnel response and decision-making under simulated threat conditions. A staged early warning mechanism can be employed to simulate escalating threat levels, such as an initial alert when personnel enter a monitored area and a secondary alert when they approach a critical target zone. These alerts may be integrated with audio alarms or simulated effects to enhance training realism while maintaining safety through controlled activation and remote supervision.

This paper proposes a microcontroller-based Arduino Nano and ESP32 object movement detection system utilizing a PIR sensor, an ultrasonic sensor, and a GPS module for military training applications. The system is designed to provide multi-level early warnings, real-time troop position monitoring, and wireless data transmission to a centralized server. The proposed approach aims to enhance training safety, improve monitoring efficiency, and support controlled simulation scenarios. The system is expected to serve as a modular and scalable platform that can be further developed for advanced military training environments and integrated security systems.

System Architecture And Related Works

A. Related Works

Several studies have explored the application of sensor-based systems for movement detection, security monitoring, and location tracking in various domains, including facility security, asset protection, and surveillance systems. Based on the research by (Handayani, R., 2022) demonstrated that the integration of a Passive Infrared (PIR) sensor with a microcontroller-based platform Arduino Nano and ESP32 was effective in detecting human movement and triggering alarm notifications in security applications. The PIR sensor was able to identify motion based on infrared radiation changes, making it suitable for low-power and real-time monitoring systems.

Further research has investigated the combination of PIR and ultrasonic sensors to enhance detection reliability. According to the study by (Candra, J. E., & Nugroho, D., 2025), a dual-sensor approach was implemented using a PIR sensor for initial motion detection and an ultrasonic sensor for distance measurement. The results showed that combining both sensors significantly reduced false detections and

improved accuracy compared to single-sensor systems. The ultrasonic sensor enabled precise measurement of object distance, which was particularly useful for determining proximity levels in restricted areas.

The use of Global Positioning System (GPS) technology in monitoring and tracking applications has also been widely reported. Studies such as (Almasdih, D., & Diantoro, K., 2025) implemented GPS modules to track the real-time location of moving objects and transmit positional data to a remote monitoring system. The integration of GPS with wireless communication modules allowed centralized monitoring and improved situational awareness, especially in outdoor environments.

In military and tactical training contexts, sensor-based early warning systems have been introduced to simulate threat scenarios and enhance personnel readiness. Based on the research by (Kuswana, A., & Durahman, N., 2024) highlighted the importance of multi-level warning mechanisms to train response behavior under simulated intrusion conditions. These systems utilized alarm actuators and centralized monitoring to ensure controlled and safe training environments. However, most existing

systems focus on individual sensing mechanisms and lack comprehensive integration of motion detection, distance measurement, and real-time positioning in a unified architecture.

Based on the limitations identified in previous studies, this research proposes an integrated system combining PIR sensors, ultrasonic sensors, and GPS technology within a microcontroller-based Arduino Nano and ESP32 framework. The proposed system is specifically designed for military training applications, providing multi-stage early warnings, real-time location monitoring, and centralized control to improve training safety and operational effectiveness.

B. System Architecture

The envisaged system architecture includes several modules interconnected to function motion detection, distance measurement, location finding, alarm simulation, and wireless data transfer. It is set in three big parts: the perception layer, the control and processing layer and the communication, monitoring level. An infrared detector module is composed of the PIR sensor section.

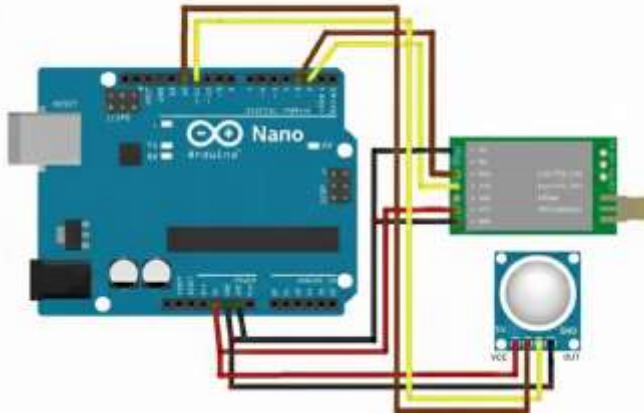


Figure1 PIR Sensor Circuit

In Figure 1, the PIR sensor works in tandem with the Arduino Nano and ESP32 microcontroller unit. The PIR sensor is the first-level movement detection element and it can distinguish human body emitted infrared radiation production through changes occurring in those emissions. When the sensor detects motion, it outputs a digital signal to the microcontroller, causing the entire system to enter active monitoring mode from an initial period of waiting. This first detection alarm stage is the first formal stage of warning in the proposed architecture.

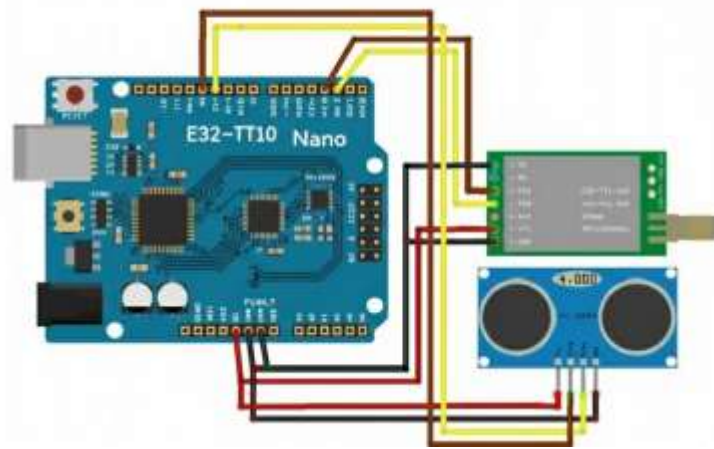


Figure 2 Ultrasonic Sensor Circuit

Figure 2 shows the ultrasonic sensor circuit for the purpose of distance measurement. Ultrasonic Sensor Circuit. After receiving a motion signal from the PIR sensor, the microcontroller triggers the ultrasonic sensor circuit to measure distance between detected object and pre-set critical area. The ultrasonic sensor uses time-of-flight principle of ultrasonic waves for its operation rationale. Then, the distance actually measured will be processed to decide whether or not an object has got over a warning threshold. This ensures multilevel warning simulation can be implemented.

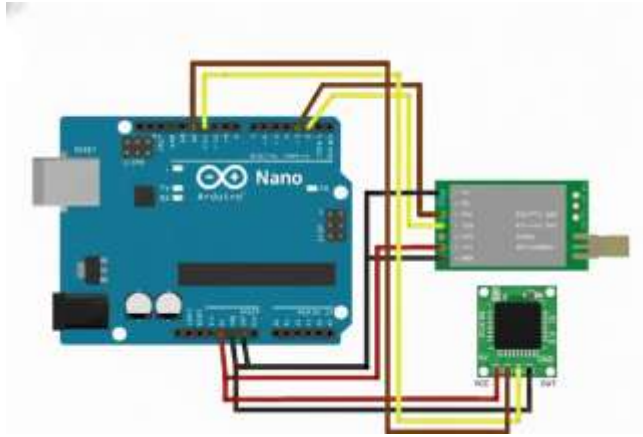


Figure 3 Ultrasonic Sensor Circuit

Figure 3 depicts the LoRa SX1278 communication module integrated into the system architecture. LoRa Communication Architecture. The LoRa module transmits sensor data, warning status and GPS location wirelessly to a centralized monitoring server via longrange, low power consumption communications. Such a layer of communication allows instructors to follow the movements of their troops out in real time.

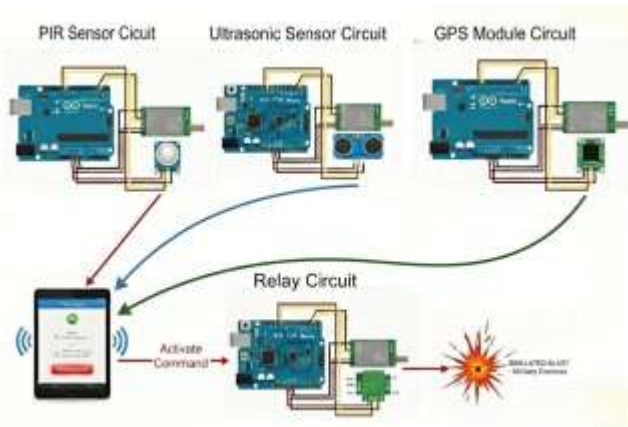


Figure 4 Blash Simulation

The Blash simulation mechanism, Figure 4. When the detected object reaches a set

critical distance, phased flash (explosion) simulation output, such as alarm sound and visual indicator, can be activated. This firing up in succession makes it more like practice and yet at the same time maintains GPS-based monitoring and central control of operations for safety.

Methodology

This section describes the research methodology used in designing, implementing, and evaluating the proposed object movement detection system for military training applications. The methodology includes system design procedures, hardware and software implementation, operational workflow, and testing scenarios to evaluate system performance.

A. Research Method

This research adopts an engineering-based experimental method focused on the development and validation of a prototype system. The methodology involves designing a microcontroller-based Arduino Nano and ESP32 detection system that integrates a Passive Infrared (PIR) sensor, an ultrasonic sensor, and a Global Positioning System (GPS) module to support multi-level early warning

mechanisms. The system is developed to simulate controlled threat detection scenarios in military training environments.

The research stages consist of requirement analysis, system design, hardware integration, software development, system testing, and performance evaluation. Each stage is conducted systematically to ensure that the resulting system meets functional and safety requirements for training operations.

B. Hardware Configuration

The hardware configuration of the proposed system consists of a microcontroller Arduino Nano and ESP32 as the central processing component, interfaced with a PIR sensor, an ultrasonic sensor, a GPS module, and an alarm actuator. The PIR sensor is utilized as the primary motion detection component, capable of identifying human movement based on infrared radiation variations. The ultrasonic sensor is responsible for measuring the distance between the detected object and the predefined target zone using ultrasonic wave reflection.

The GPS module is attached to training personnel to continuously acquire real-time positional data in the form of latitude and longitude coordinates. This information

enables remote monitoring and ensures that simulated warning or explosion events are triggered only when personnel are located within safe operational distances. An alarm actuator, such as a buzzer, is integrated to generate immediate auditory warnings when specific detection conditions are met.

C. Software Design and Algorithm

The system software is developed to manage sensor data acquisition, decision-making logic, warning generation, and data transmission. The microcontroller Arduino Nano and ESP32 executes a continuous monitoring loop that begins with PIR sensor initialization and motion detection. When movement is detected, the system activates the ultrasonic sensor to measure object distance.

Distance thresholds are defined to implement a multi-stage warning mechanism. If the measured distance exceeds the critical threshold, the system issues an initial warning. When the object approaches the predefined critical distance, a secondary warning is triggered, activating the alarm actuator and transmitting an alert to the server. Simultaneously, GPS data is continuously read and transmitted to the

monitoring server to update personnel position in real time.

D. Operational Workflow

The operational workflow of the system begins with system initialization, including sensor calibration and communication setup. The system then enters a standby monitoring state. When motion is detected by the PIR sensor, the system transitions into an active detection mode, enabling ultrasonic distance measurement and warning evaluation.

Based on the detected distance and predefined safety parameters, the system generates corresponding warning levels. Local warnings are delivered through alarm actuators, while remote notifications and positional data are sent to the server for centralized monitoring. This workflow ensures both immediate local response and remote supervision throughout the training session.

E. Testing Scenarios

System testing is conducted under simulated military training conditions to evaluate detection accuracy, response time, and reliability. Several test scenarios are designed, including stationary and moving personnel detection, varying

distance measurements, and GPS tracking in open-field environments.

Each scenario is evaluated based on the system's ability to detect movement accurately, measure distance within acceptable error margins, trigger warnings at appropriate thresholds, and transmit positional data reliably. The results of these tests are analyzed to assess system performance and identify potential improvements for future development.

Results and Discussion

This section presents the experimental results of the proposed system in quantitative and qualitative forms, including tabulated data, graphical analysis, and detailed performance discussion. The evaluation focuses on PIR motion detection accuracy, ultrasonic distance measurement accuracy, GPS tracking performance, system response time, and the effectiveness of the multi-level warning mechanism in military training simulations.

A. PIR Sensor Motion Detection Results

The PIR sensor was tested to evaluate its capability in detecting human movement at various distances and movement conditions. The testing scenarios included different distances between the sensor and

the moving object, as well as variations in movement direction.

Table I presents the PIR sensor detection results.

Table 1
 PIR Sensor Detection Performance

Distance	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Detection rate %
2 meters	Detected	Detected	Detected	Detected	Detected	100%
4 meters	Detected	Detected	Detected	Detected	Detected	100%
6 meters	Detected	Detected	Detected	Not Detected	Detected	80%
8 meters	Not Detected	Detected	Not Detected	Detected	Not Detected	40%
10 meters	Not Detected	Not Detected	Not Detected	Not Detected	Not Detected	0%

Based on Table 1, the PIR sensor demonstrated optimal performance within a range of 2–6 meters. Detection accuracy decreased as distance increased beyond the effective sensing range. This behavior aligns with the physical characteristics of PIR sensors, which rely on infrared

radiation changes and are sensitive to environmental conditions.

A graphical representation (Table 1) illustrates the relationship between detection success rate and distance, showing a downward trend as distance increases.

B. Ultrasonic Sensor Distance Measurement Analysis

The ultrasonic sensor was evaluated by comparing measured distances with actual distances. The objective was to determine measurement accuracy and reliability for proximity-based warning generation.

Table 2
 Ultrasonic Sensor Distance Accuracy

Actual Distance	Reading 1(cm)	Reading 2(cm)	Reading 3(cm)	Reading 4(cm)	Reading 5(cm)	Average	Error
50 cm	50,82	51,14	51,03	50,67	50,91	50,91	+0,91
100 cm	101,76	102,34	102,11	101,98	101,89	102,02	+2,02
150 cm	152,48	153,12	153,41	152,95	152,76	152,94	+2,94
200 cm	205,37	206,82	206,15	205,94	206,43	206,14	+6,14

The results indicate that measurement error increases with distance. However, within

the critical range used for warning thresholds (≤ 150 cm), the error remains within acceptable limits for military training simulations. Table 2 illustrates the linear trend between actual and measured distances, confirming stable ultrasonic sensor performance.

C. GPS Tracking Performance Evaluation

The GPS module was tested for real-time position tracking accuracy in open-field environments. The measured GPS coordinates were compared with reference positions obtained from standard mapping tools.

Table 3

GPS Tracking Accuracy

Test Location	Latitude, Longitude	Reference Coordinate	Position Error
Point A	- 7,895013, 112,5836 91	- 7,895030, 112,5836 87	2.34 meters
Point B	- 7,894912, 112,5847 66	- 7,894905, 112,5847 47	3.12 meters
Point C	- 7,894457, 112,5853	- 7,894446, 112,5853	3.78 meters

	78	78	
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The GPS tracking error remained within 2–4 meters, which is acceptable for monitoring troop movement during training exercises. Table 3 illustrates the tracked path versus the actual movement path, showing a close correlation between both trajectories.

D. System Response Time Analysis

System response time was measured from the moment motion was detected by the PIR sensor until the warning actuator was activated and data was transmitted to the server.

Table 4

System Response Time

Proses	Tri al 1	Tri al 2	Tri al 3	Tri al 4	Tri al 5	Averag e(ms)
PIR Detecti on	17 6	18 2	17 9	18 5	18 1	180,6
Ultraso nic Distanc e Proces sing	11 8	11 3	12 1	11 9	12 4	121,0

Alarm Activati on	87	92	89	91	90	89,8
Data Transm ission to Server	30 5	31 8	31 2	30 9	32 1	313,0

The total response time remained below 1 second, indicating that the system is capable of providing near real-time warnings. Table 4 shows the response time distribution for each system process, highlighting efficient system performance suitable for training simulations.

E. Multi-Level Warning System Evaluation

The staged warning mechanism was tested by simulating troop movement toward a predefined target area. The PIR sensor provided the initial warning when movement was detected, while the ultrasonic sensor triggered a secondary warning upon reaching a critical distance.

The results confirm that the multi-level warning system functioned as intended, enabling realistic threat simulation while maintaining safety. This staged approach supports tactical training by enhancing

situational awareness and encouraging appropriate response behavior.

F. Discussion

From the experimental results, it can be concluded that the integration of PIR, ultrasonic, and GPS sensors significantly improves system reliability compared to single-sensor systems. The use of tables and graphical analysis demonstrates consistent performance across detection, distance measurement, and location tracking metrics.

The proposed system effectively supports military training requirements by offering accurate movement detection, controlled warning activation, and real-time monitoring. Although minor limitations were observed under extreme conditions, these do not significantly impact system usability. Future work may focus on sensor fusion algorithms, extended communication range, and enhanced environmental robustness.

Conclusion

This paper has presented the design and implementation of an integrated object movement detection system utilizing a Passive Infrared (PIR) sensor, an ultrasonic

sensor, and a Global Positioning System (GPS) module for military training applications. The proposed system was developed to support controlled training simulations by providing multi-level early warnings and real-time position monitoring of training personnel. The integration of multiple sensors within a microcontroller-based Arduino Nano and ESP32 architecture enables reliable movement detection, accurate distance measurement, and continuous location tracking.

Experimental results demonstrate that the PIR sensor effectively detects human movement within its optimal sensing range, while the ultrasonic sensor provides sufficient distance measurement accuracy to support proximity-based warning mechanisms. The GPS module successfully delivers real-time positional data with acceptable accuracy for monitoring troop movement in outdoor training environments. The overall system response time remains within near real-time limits, ensuring timely warning delivery and operational safety during training exercises.

The staged warning mechanism implemented in the system proves effective in simulating tactical threat scenarios while maintaining safe operational conditions. By combining local alarm activation and centralized monitoring through telemetry

communication modul LoRa SX1278, the system enhances situational awareness for both training personnel and instructors.

In conclusion, the proposed system offers a practical, modular, and scalable solution for military training support, particularly in movement detection and early warning applications. Future work may focus on integrating additional sensors, improving sensor fusion algorithms, enhancing communication reliability, and expanding system deployment for larger and more complex training environments.

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