



# TERRAPULSE-X: INTELLIGENT HUMAN PRESENCE DETECTION BENEATH RUBBLE USING SENSOR FUSION AND PREDICTIVE ANALYTICS

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**Abstract:** Natural disasters such as landslides and structural collapses often leave victims trapped beneath debris, where rapid detection is critical for survival. TerraPulse-X presents an intelligent human presence detection system that combines sensor fusion and predictive analytics to support search and rescue operations. The proposed framework integrates ultrasonic, vibration, sound, and DHT11 temperature humidity sensors with an ESP32 microcontroller for continuous environmental monitoring. Sensor readings are collected, processed, and transmitted to a Flask-based monitoring platform through serial communication for real-time visualization and analysis. Historical data obtained from the sensing modules are utilized to train a Linear Regression model capable of forecasting future distance, temperature, and humidity values. The predictive capability assists rescue personnel in identifying environmental trends and potential indicators of human presence beneath rubble. An IoT-enabled notification mechanism using the Blynk platform provides immediate alerts whenever abnormal conditions or detection events occur. Experimental evaluation demonstrates reliable sensing performance, efficient data transmission, accurate prediction outcomes, and enhanced situational awareness, making the system suitable for disaster response applications and emergency rescue scenarios worldwide today.

**Index Terms** –Human Presence Detection, Sensor Fusion, ESP32, Predictive Analytics, Linear Regression, Flask Application, Blynk, IoT, Disaster Management, Search and Rescue Operations, Rubble Detection.

## I. INTRODUCTION

Advancements in embedded systems, wireless communication, and intelligent sensing technologies have created new opportunities for developing smart monitoring solutions capable of operating in challenging environments. Sensor-based detection systems are increasingly being adopted in safety-critical applications because of their ability to provide continuous monitoring, rapid response, and reliable decision support. By combining multiple sensing mechanisms with data analytics, such systems can collect valuable environmental information and transform it into actionable insights. The integration of Internet of Things (IoT) technologies further enhances system capabilities by enabling remote monitoring, real-time data transmission, and automated alert generation, making intelligent sensing platforms highly suitable for emergency response applications. Natural disasters such as landslides, earthquakes, and building collapses frequently result in people becoming trapped beneath debris and rubble. In such situations, the first few hours are crucial for survival, and any delay in locating victims can significantly reduce rescue success

rates. Conventional search and rescue methods, including manual inspection, trained rescue dogs, and thermal imaging equipment, often face limitations in complex environments where visibility is poor and access is restricted. These challenges highlight the need for cost-effective and reliable technological solutions capable of detecting human presence beneath obstructed surfaces. TerraPulse-X presents an intelligent human presence detection system designed to assist rescue personnel during disaster response operations. The proposed framework utilizes sensor fusion by integrating ultrasonic, vibration, sound, and DHT11 temperature-humidity sensors with an ESP32 microcontroller. The collected sensor data are processed and transmitted to a Flask-based monitoring platform through serial communication, allowing real-time visualization and analysis of environmental conditions. To enhance system intelligence, historical sensor readings are employed to train a Linear Regression model that predicts future temperature, humidity, and distance values. These predictive insights support informed decision-making and improve situational awareness during rescue missions. In addition, IoT connectivity through the Blynk platform enables instant alerts and notifications whenever abnormal conditions or potential signs of human presence are detected. The combination of multi-sensor data acquisition, predictive analytics, real-time monitoring, and automated notification mechanisms contributes to a practical and scalable solution for improving the efficiency and effectiveness of search and rescue operations in disaster-affected areas.

## II. RELATED WORKS

**Article [1] "A Review on Radar-Based Human Detection Techniques" by Muhammet Talha Buyukakkaslar, Mehmet Ali Erturk, and Muhammet Ali Aydin in 2024:** Radar-based human detection has gained significant attention for search and rescue applications. The study presents a comprehensive review of micro-Doppler radar technologies used for human recognition and detection. Different radar architectures, signal processing techniques, and machine learning approaches are analyzed. The authors discuss the ability of radar systems to operate effectively under adverse weather and low-visibility conditions. The review highlights applications in healthcare, security, transportation, and disaster management.

**Article [2] "Unmanned Aerial Vehicles for Search and Rescue: A Survey" by Mingyang Lyu, Yibo Zhao, Chao Huang, and Hailong Huang in 2022:** The paper presents a detailed survey of unmanned aerial vehicles employed in search and rescue operations. Various UAV platforms, onboard sensors, communication systems, and navigation mechanisms are reviewed. The authors discuss the role of thermal cameras, optical imaging systems, and artificial intelligence algorithms in victim detection. The survey highlights the advantages of UAVs, including rapid deployment, high mobility, and wide-area coverage. Several challenges such as limited battery life, environmental constraints, and communication reliability are examined. Different search strategies and autonomous navigation techniques are also analyzed. The study provides valuable recommendations for enhancing future UAV-assisted rescue missions.

**Article [3] "A Survey of Disaster Management and SAR Operations Using Sensors and Supporting Techniques" by Zahraa Tarik Al Ali and Salah Abdulghani Alabady in 2022:** This survey investigates modern sensor technologies used in disaster management and search-and-rescue operations. The authors review thermal sensors, optical cameras, wireless sensor networks, and environmental monitoring devices. Various victim detection and localization techniques are compared based on performance and reliability. The paper discusses communication technologies that support emergency response systems. Challenges associated with real-time monitoring and large-scale deployment are highlighted.

**Article [4] "The Use of Decision Support in Search and Rescue" by W. Nasar, S. H. Alshammari, and M. Alruwaili in 2023:** This paper investigates the application of decision support systems in modern search and rescue operations. The study examines how artificial intelligence, geographic information systems, and data analytics can improve emergency response activities. Various rescue scenarios are analyzed to understand the effectiveness of automated decision-making tools. The authors discuss the importance of situational awareness and resource allocation during critical rescue missions. Different technologies are evaluated based on their ability to enhance rescue efficiency and response time.

**Article [5] "Sensors on the Internet of Things Systems for Urban Disaster Management: A Systematic Review" by Feng Zeng, Yao Wang, and Xiaofeng Li in 2023:** This review focuses on the integration of IoT sensors in disaster management systems. The authors analyze various sensing devices used for environmental monitoring, structural health monitoring, and emergency response. Different communication protocols and cloud platforms are discussed in detail. The paper highlights how IoT technology enables real-time monitoring and rapid information sharing during disasters. Several case studies are examined to evaluate system performance and reliability. Challenges related to security, scalability, and interoperability are also presented.

**Article [6] "AI-Enhanced UAV Clusters for Search and Rescue in Disaster Environments" by A. ZaidAlkilani, M. Alotaibi, and K. Alharbi in 2025:** This research explores the use of artificial intelligence and unmanned aerial vehicle clusters in search and rescue operations. The proposed system employs advanced sensors and AI algorithms to detect and locate victims in disaster-affected regions. Autonomous coordination among multiple UAVs improves search coverage and operational efficiency. The study evaluates object detection, path planning, and target localization techniques. Experimental results indicate improved accuracy and reduced search time. The authors discuss the importance of integrating intelligent technologies into emergency response systems.

**Article [7] "Low-Cost Real-Time Remote Sensing and Geolocation of Disaster Events" by Pengfei Sun, Jun Li, and Ming Zhao in 2025:** The paper presents a cost-effective framework for disaster monitoring using remote sensing technologies. Various environmental sensors and geolocation mechanisms are integrated into the proposed system. Real-time monitoring allows emergency teams to identify affected areas quickly and accurately. The authors discuss methods for collecting, processing, and visualizing disaster-related information. The study emphasizes affordability and accessibility for developing regions. Experimental results demonstrate reliable performance under different environmental conditions.

**Article [8] "Experimental Validation of UAV Search and Detection Systems" by S. Dumenčić, M. Jovanović, and D. Petrović in 2025:** This study evaluates the effectiveness of UAV-based search and detection systems through extensive experimental testing. Different sensor configurations are analyzed to determine their impact on victim detection accuracy. The authors investigate navigation performance, communication reliability, and data acquisition capabilities. Real-world experiments demonstrate the usefulness of UAV platforms in emergency situations. Several operational challenges related to weather and terrain are discussed.

**Article [9] "Cultivating Disaster Preparedness: Scoping Review of Technology-Enabled Disaster Education" by Amir Khorram-Manesh, Sara Berlin, and Helena Nilsson in 2025:** This review examines how emerging technologies can enhance disaster preparedness and emergency response awareness. Various educational platforms, simulation tools, and monitoring technologies are analyzed. The study highlights the importance of integrating intelligent systems into disaster management frameworks. Digital technologies are shown to improve training effectiveness and situational understanding. Challenges associated with technology adoption and implementation are also discussed.

**Article [10] "A Comparative Analysis of UAVs and UGVs for Disaster Response" by A. K. Sharma, P. Verma, and R. Gupta in 2025:** This paper compares unmanned aerial vehicles and unmanned ground vehicles in disaster response applications. Different operational characteristics such as mobility, sensing capability, and deployment flexibility are evaluated. The authors discuss the strengths and limitations of each platform in various rescue scenarios. Several case studies are reviewed to assess system performance. Real-time monitoring and victim detection capabilities are analyzed in detail. Challenges involving communication and environmental constraints are examined. The study provides guidance for selecting suitable autonomous platforms in emergency situations.

**Article [11] "Flood Detection with SAR: A Review of Techniques and Applications" by Daniele Amitrano, Antonio Chianese, and Gilda Schirinzi in 2024:** This review explores the application of Synthetic Aperture Radar technology in disaster monitoring and flood detection. Various SAR-based methodologies and image processing techniques are discussed. The authors analyze the advantages of radar systems in adverse weather and low-visibility conditions. Applications in environmental monitoring and

emergency response are highlighted. Challenges associated with data interpretation and computational complexity are examined. The paper reviews recent advancements in SAR technology and their practical benefits.

**Article [12] "A FSK Radar With Frequency-Scanned Array for Moving Human Detection" by Yongjian Wang, Yu Zhang, and Wei Liu in 2021:** This paper proposes a frequency-shift keying radar system designed for accurate moving human detection. The radar utilizes a frequency-scanned array architecture to improve target localization performance. Advanced signal processing methods are employed to identify human movement patterns. Experimental evaluations demonstrate high detection accuracy and reliable operation. The authors discuss potential applications in security monitoring, surveillance, and rescue operations. System performance is analyzed under different environmental conditions.

### III. PROBLEM STATEMENT

Locating survivors trapped beneath rubble after landslides, earthquakes, and structural collapses remains a major challenge for rescue teams. Conventional search and rescue methods often suffer from limited detection accuracy, delayed response times, high operational costs, and difficulties in inaccessible environments. Environmental noise, poor visibility, and unstable debris further reduce the effectiveness of victim detection. Existing systems may rely on a single sensing technology, leading to false alarms or missed detections. Additionally, the lack of real-time monitoring and predictive analysis limits situational awareness during rescue operations. Therefore, an efficient, reliable, and intelligent system is required to accurately detect human presence beneath rubble and provide timely alerts for rescue personnel.

### IV. OBJECTIVES

The primary objective of this study is to develop an intelligent system capable of detecting human presence beneath rubble using multiple sensors and sensor fusion techniques. The study aims to collect and analyze data from ultrasonic, vibration, sound, and temperature-humidity sensors to improve detection accuracy. Another objective is to implement real-time monitoring through a Flask-based application for effective visualization of sensor readings. The study also seeks to utilize Linear Regression for predicting future environmental conditions based on historical data. Additionally, it aims to provide instant alerts and notifications through IoT connectivity, enabling faster response and improved decision-making during search and rescue operations..

### V. METHODOLOGY

**1)Sensor Data Collection:** The methodology begins with collecting environmental data using multiple sensors connected to the ESP32 microcontroller. An ultrasonic sensor measures distance variations, while the DHT11 sensor records temperature and humidity values. The sound sensor captures acoustic signals and the vibration sensor detects movements or tremors beneath the rubble. Continuous data collection from multiple sources improves the reliability of human presence detection.

**2)Data Acquisition and Processing:** The ESP32 microcontroller receives sensor readings from all connected sensors and performs preliminary processing. The collected data is filtered to reduce noise and remove unwanted fluctuations that may affect system performance. Sensor values are converted into meaningful information for analysis and monitoring. This processing stage improves the accuracy and consistency of the detection system.

**3)Serial Communication with Flask Server:** After processing, the sensor readings are transmitted from the ESP32 to the Flask application through serial communication. The Flask server continuously receives and updates sensor values in real time. This communication mechanism ensures reliable data transfer between hardware and software components. It also enables centralized monitoring of all environmental parameters through a single platform.

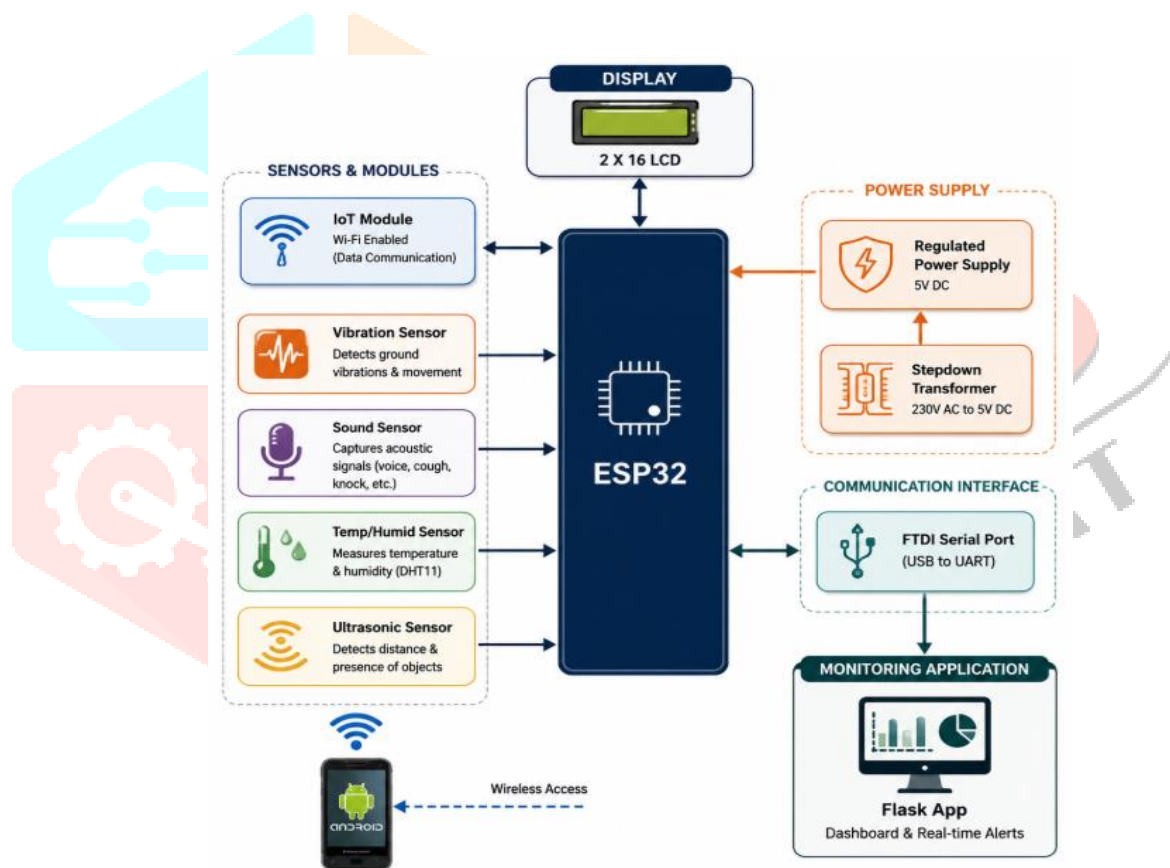
**4)Data Storage and Historical Analysis:** The Flask application stores the incoming sensor readings for future reference and analysis. Historical records of temperature, humidity, distance, sound, and vibration values are maintained systematically. The stored data helps identify environmental trends and behavioral patterns over time. It also serves as the dataset required for predictive analytics.

**5) Predictive Analytics Using Linear Regression:** A Linear Regression algorithm is applied to historical sensor data to predict future environmental conditions. The model is trained using previously collected temperature, humidity, and distance readings. Based on learned trends, future values are estimated to support decision-making during rescue operations. This predictive capability enhances the intelligence of the proposed system.

**6) Real-Time Monitoring and Visualization:** The Flask dashboard displays current sensor readings along with predicted values through an interactive interface. Graphs, charts, and status indicators provide a clear view of environmental conditions. Rescue personnel can monitor the situation remotely and continuously. Real-time visualization improves situational awareness and operational efficiency.

**7) Alert Generation and Notification System:** Whenever abnormal sensor readings or possible signs of human presence are detected, the system generates alerts automatically. The ESP32 uses Wi-Fi connectivity to communicate with the Blynk platform and send instant notifications. Alert messages are displayed on the dashboard and can be accessed remotely by rescue personnel. This feature enables faster response times and supports effective search and rescue operations.

## VI. SYSTEM ARCHITECTURE

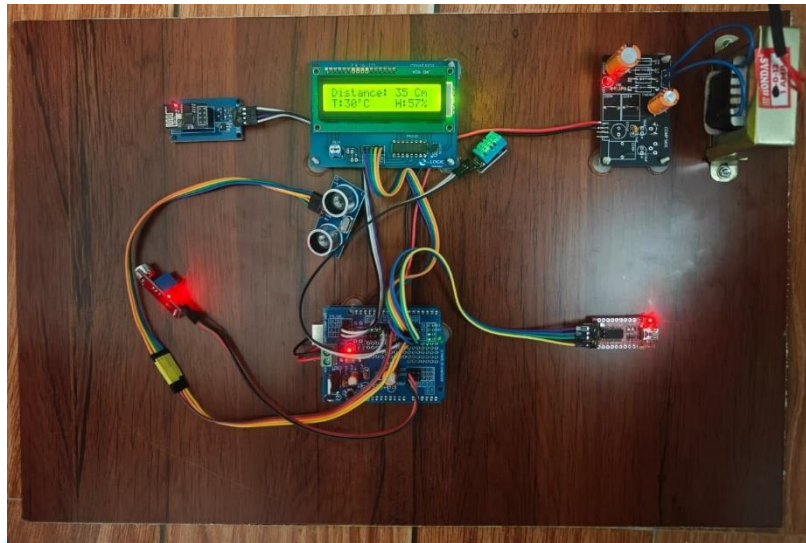


**Fig 1: Proposed System Architecture of TerraPulse-X for Human Presence Detection and Predictive Analytics**

The proposed system architecture is designed to detect human presence beneath rubble using multiple sensors, predictive analytics, and IoT communication. At the core of the system is the ESP32 microcontroller, which acts as the central processing unit and interfaces with all sensing modules. The ultrasonic sensor measures distance variations, while the DHT11 sensor monitors temperature and humidity conditions. In addition, the sound sensor captures acoustic signals such as voices or knocks, and the vibration sensor detects ground movements that may indicate human activity. The collected sensor data is processed by the ESP32 and transmitted to a Flask-based monitoring application through the FTDI serial communication interface. The Flask application displays real-time sensor readings, stores historical data, and supports data analysis. A Linear Regression algorithm utilizes the stored sensor data to predict future temperature, humidity, and distance values, providing valuable insights for rescue operations. Furthermore,

the ESP32 communicates with the Blynk platform through Wi-Fi to generate instant alerts and notifications whenever abnormal conditions or potential signs of human presence are detected.

## VII. EXPERIMENTAL SETUP



**Fig. 2: Hardware Prototype of TerraPulse-X Intelligent Human Presence Detection System**

The figure shows the developed hardware prototype of the TerraPulse-X system consisting of an ESP32 microcontroller, ultrasonic sensor, vibration sensor, DHT11 temperature-humidity sensor, LCD display, and power supply unit.

## VIII. CONCLUSION AND FUTURE WORKS

In this research, an intelligent human presence detection system was developed using ESP32, multiple sensors, predictive analytics, and IoT technologies to support search and rescue operations. The integration of ultrasonic, vibration, sound, and temperature-humidity sensors enabled reliable monitoring of environmental conditions and potential human activity beneath rubble. Real-time visualization through a Flask application and instant notifications through the Blynk platform enhanced situational awareness and response efficiency. Future work can focus on integrating advanced machine learning algorithms, additional sensing technologies, and wireless communication methods to improve detection accuracy. The system can also be extended for large-scale disaster management applications.

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