

Literature Survey on ESP32-Based Multi-Sensor Fusion for Disaster Survivor Detection and Post-Disaster Search & Rescue

Pranit Pendhari¹, Mohit Durgavale², Aryan Shelar³, Harshad Pachupate⁴, Ashok Mane⁵

Department of Electronics and Telecommunication Engineering, Terna Engineering College, Navi Mumbai, India

Abstract— Post-disaster search and rescue requires rapid identification of locations where living survivors may be trapped. This literature survey reviews technologies relevant to a compact, low-cost survivor-detection rover using ESP32-based edge processing. The reviewed work covers microwave and Doppler life detection, thermal imaging, acoustic sensing, multi-sensor fusion, embedded processing, and infrastructure-independent wireless communication. Microwave sensing can detect micro-motion without direct visibility, but inexpensive continuous-wave sensors provide limited spatial information. Thermal arrays such as the MLX90640 can locate exposed warm regions in darkness but cannot see through opaque debris. Acoustic sensing can capture voice or tapping but is sensitive to noise and attenuation. The survey therefore supports a multi-sensor approach in which independent cues are processed locally and combined to improve confidence. The proposed system uses a single ESP32 board to control rover movement and survivor-detection functions, integrating sensor acquisition, thermal analysis, data processing, and alert generation within one embedded platform. This unified architecture simplifies hardware integration while enabling the mobile rover to navigate constrained debris zones and identify potential survivor indications.

I. INTRODUCTION

Earthquakes, landslides and structural collapses can leave survivors trapped beneath or inside unstable debris. During the first hours of rescue, responders often depend on visual inspection, voice contact, trained dogs and specialised life-detection instruments. These methods are valuable, but difficult access, unstable structures and the cost of advanced equipment can restrict how quickly an area can be searched.

A compact robotic platform can reduce the need for rescuers to enter dangerous spaces during the initial search. The rover can move into narrow or unstable areas while carrying sensors that observe different signs of human presence. The proposed project follows this concept by combining a motion/radar sensing channel with a 7Semi MLX90640 32×24 infrared thermal camera and ESP32-based processing. The mobile rover is powered by a 3S 18650 lithium-ion battery pack with BMS and uses a motor driver, BO motors and an LM2596S buck converter for regulated electronics supply.

No single low-cost sensor can reliably identify a trapped person in every situation. Thermal sensing is useful when body heat is exposed, but opaque debris blocks long-wave infrared radiation. Radar or motion sensing can respond without visible light, but low-cost sensors have limited ranging or localisation capability. This motivates a multi-sensor architecture in which each channel contributes evidence rather than making the entire decision alone.

II. LITERATURE REVIEW ON DISASTER SURVIVOR DETECTION

In this review, selected research and technical works are studied according to their relevance to survivor detection, sensing, embedded processing and rescue communication.

A. Microwave Life-Detection Systems

Chen et al. [1] developed microwave life-detection techniques for locating human subjects behind barriers and under earthquake rubble. The work uses microwave reflections to detect very small periodic body movements related to respiration and heartbeat. Its major advantage is non-contact detection when direct optical visibility is unavailable. The limitation is the specialised RF hardware and signal-processing complexity. The study provides an important technical foundation for the motion/radar sensing part of the proposed survivor-detection rover. In practical rubble environments, reflected signals can also contain strong clutter from stationary construction material and unrelated movement. This reinforces the need for filtering, repeated observations and confirmation from another sensing modality before declaring a survivor.

B. Noninvasive Microwave Measurement of Respiration

Lin [2] demonstrated that respiration can be measured without physical contact using microwave techniques. The reflected signal changes with chest-wall motion during breathing. This early work establishes the physical principle behind radar-based vital-motion sensing. For the proposed system, it supports the idea of using microwave motion information as one indication of possible human presence, while recognising that a low-cost implementation cannot be treated as a clinical vital-sign monitor.

The important design lesson is that very small periodic movement can carry useful information even when a camera cannot directly observe the person.

C. See Through Walls with WiFi

Adib and Katabi [3] showed that radio-frequency reflections can be processed to detect human movement even when a person is behind a wall. The key benefit is sensing without direct line of sight. However, the approach requires sophisticated signal processing and is not designed as a simple low-cost rescue module. It is relevant mainly because it demonstrates that RF reflections can carry useful information about hidden human motion. For the proposed rover, this supports the broader use of radio sensing while favouring a dedicated compact sensor and simpler on-device processing.

D. Smart Homes that Monitor Breathing and Heart Rate

Adib et al. [4] extended wireless reflection sensing to breathing and heart-rate monitoring. The study demonstrates that very small body movements can be extracted from RF signals under controlled conditions. Its strength is contactless monitoring, while its limitation for disaster rescue is dependence on more advanced processing and a comparatively controlled environment. Rubble introduces irregular materials, reflections and obstruction that are different from normal indoor monitoring. The proposed project therefore uses the concept as background rather than directly reproducing the system.

E. Thermal Cameras and Applications

Gade and Moeslund [5] reviewed thermal-camera applications including human detection. Thermal sensing is valuable because it does not depend on visible illumination and can identify temperature contrast between a person and the environment. The principal drawbacks are false positives from heated objects or sunlit surfaces and the inability of thermal radiation to pass through opaque debris. This directly supports the use of the MLX90640 as a confirmation sensor rather than a stand-alone buried-person detector. On a small rover, thermal frames can still be useful for locating an exposed hand, face or body region in dark cavities where an ordinary camera may provide little information.

F. Multisensor Data Fusion Foundations

Hall and Llinas [6] presented foundational concepts for combining information from multiple sensors. The central advantage of fusion is that complementary sensors can compensate for one another's weaknesses. This is highly relevant to the proposed rover because radar/motion and thermal sensing respond to different physical properties.

Fusion can therefore reduce dependence on any single noisy measurement. A transparent fusion rule is also easier to explain, test and tune during an academic prototype than an opaque decision model.

G. Multisensor Data Fusion: State-of-the-Art

Khaleghi et al. [7] reviewed fusion methods and challenges such as uncertain measurements, conflicting evidence and sensor imperfections. The study shows that the fusion method should match the available data and validation level. For a student prototype with limited labelled rescue data, a transparent weighted or rule-based method is more defensible than claiming a highly trained artificial-intelligence classifier. Persistence rules can further reduce false alarms by requiring evidence to remain present for multiple sensing cycles.

H. Long-Range Communications in Unlicensed Bands

Centenaro et al. [8] discussed long-range, low-power communication for IoT systems. Such communication is useful in disaster areas because alert packets require little bandwidth and infrastructure may be damaged. This provides a basis for future long-range telemetry between a rover and rescue operator, although the first prototype may use local mobile control. Communication design should prioritise small status packets, alerts and sensor summaries instead of attempting to transmit high-bandwidth data continuously.

I. A Study of LoRa

Augustin et al. [9] evaluated LoRa range, data rate and energy behaviour. LoRa is well suited to status, heartbeat and survivor-alert packets rather than high-rate thermal video. Its major advantages are low power and long range, while its limitations include low throughput and region-specific radio regulations. For a future rescue version, the rover could send only essential detection results while the local ESP32 performs the heavier sensor processing.

J. Drone Surveillance for Search and Rescue

Mishra et al. [10] examined the use of unmanned platforms for disaster search and rescue. The study supports the broader idea of sending a machine into hazardous areas to collect information before exposing rescuers. Although the proposed project uses a ground rover instead of a drone, both approaches share the goal of remote sensing in unsafe environments. A ground platform is particularly relevant when inspection is required under debris, inside cavities or close to the surface where flight is not practical.

K. TensorFlow Lite Micro for TinyML

David et al. [11] demonstrated machine-learning deployment on microcontroller-class hardware. This is relevant as future scope for classifying acoustic or thermal patterns directly on an ESP32-class device. For the present system, deterministic sensing and fusion remain more appropriate until sufficient real rescue data is collected. A later TinyML stage could be trained only after collecting representative examples of survivors, environmental heat sources, vibration and other false-positive conditions.

L. ESP32 and MLX90640 Embedded Sensing

Espressif documentation [12] describes the ESP32's dual-core processor and embedded interfaces, while the Melexis MLX90640 datasheet [13] defines a 32×24 infrared temperature array suitable for low-resolution thermal mapping. Together they support an embedded architecture in which sensing, filtering, thresholding and communication can be performed without a Raspberry Pi. Separating the project across two ESP32 boards also allows the motor-control workload to remain independent from feature processing, making the overall design more modular and easier to troubleshoot.

M. Overall Observation from the Reviewed Literature

Across the reviewed work, a common engineering challenge is the difference between laboratory detection and real disaster deployment. Rubble creates irregular propagation paths, thermal occlusion, dust, vibration, motor noise and communication constraints. These observations support the proposed project's decision to use a mobile, modular architecture and to evaluate each sensing channel independently before combining them.

For the proposed rover, the literature therefore leads to four design priorities: compact sensing that can enter constrained spaces; local processing so operation does not depend on internet infrastructure; complementary sensing so one sensor can support another; and clear validation against false-positive conditions. The project is positioned as a low-cost search aid for locating areas of interest, not as a replacement for certified professional rescue radar or trained rescue teams.

III. COMPARATIVE ANALYSIS OF SYSTEM

TABLE
COMPARATIVE ANALYSIS OF SELECTED RESEARCH WORKS

Ref.	Approach / Platform	Good Point	Drawback / Gap
1	Microwave life detection (radar)	Through-barrier micro-motion	Specialised HW / processing
2	Respiration sensing (microwave)	Non-contact breathing motion	Not localisation
3-4	RF through-wall (Wi-Fi/RF)	Hidden / vital motion	Complex; controlled setting
5	Thermal human detection	Darkness; temp. contrast	Surface-only; false positives
6-7	Multi-sensor fusion	Complementary evidence	Needs tuned weights
8	Remote platform (drone)	Reduces responder exposure	Different mobility
9	TinyML (MCU ML)	Future classification	Needs dataset
10-11	ESP32 + MLX90640	Low-cost edge processing	Limited RAM / resolution

Based on the comparative analysis, no single sensing method fully satisfies the requirements of an affordable post-disaster search device. Radar-based approaches are valuable for hidden motion, thermal sensing is useful for exposed body heat, and multi-sensor fusion provides a method for combining uncertain evidence. The proposed system therefore integrates complementary sensing on a mobile ESP32 platform while retaining clear boundaries for what each sensor can and cannot detect.

IV. BLOCK DIAGRAM OF PROPOSED SYSTEM

The proposed survivor-detection rover uses a single ESP32 microcontroller to control rover movement and survivor-detection operations. The ESP32 receives wireless commands from a mobile device and controls the BO motors through a motor driver. It also interfaces with the mmWave sensor for motion and micro-motion detection and the 7Semi MLX90640 infrared thermal camera for temperature mapping. The thermal camera provides a 32×24 pixel array, 110° field of view, and I²C communication interface.

The system architecture integrates motor control, sensor acquisition, data processing, and alert generation within a single ESP32 platform. Sensor readings are processed and combined to identify possible survivor indications, which are communicated to the operator through the mobile interface. The system is powered by a 3S 18650 lithium-ion battery pack with an integrated Battery Management System (BMS), while an LM2596S buck converter provides regulated power to the electronic components. This compact architecture reduces hardware complexity and supports operation in confined disaster-affected areas.

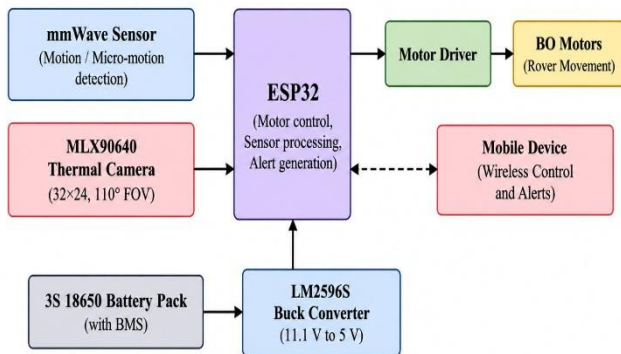


Figure 1. Proposed ESP32-based disaster survivor detection rover block diagram.

V. FLOW OF PROPOSED SYSTEM

During operation, the user controls the rover from a mobile device and drives it into an area that is unsafe or difficult to access directly. The feature-control ESP32 continuously acquires data from the survivor-detection sensors. Thermal frames are examined for warm regions while the mmWave sensing channel is processed for relevant movement. After filtering and thresholding, the evidence is combined to determine whether a possible survivor indication should be presented to the operator.

The operational sequence is as follows: (1) Power on the system and initialise the ESP32 and connected peripherals; (2) receive mobile drive commands; (3) control rover movement through the motor driver; (4) acquire mmWave and thermal sensor data; (5) filter and process the sensor readings; (6) evaluate and combine the available evidence to identify a possible survivor; and (7) generate or display an alert to the operator when the detection criteria are satisfied.

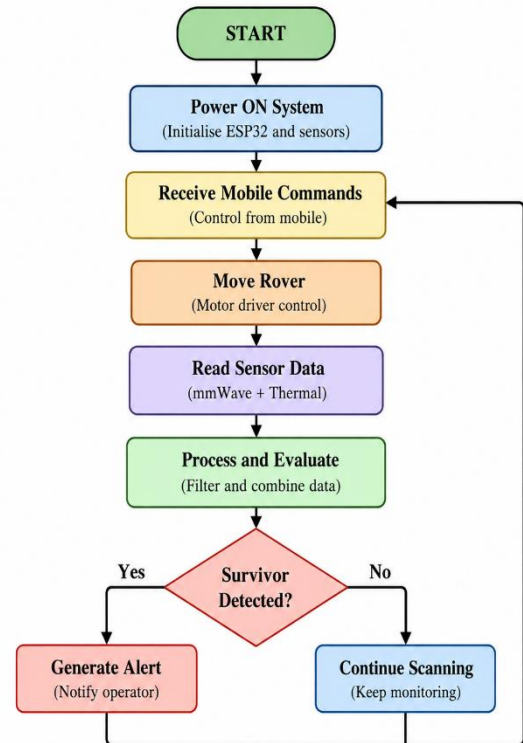


Figure 2. Flowchart of the proposed survivor-detection rover.

VI. CONCLUSION

The literature indicates that radar/RF sensing, thermal imaging, multi-sensor fusion and embedded edge processing are relevant to post-disaster survivor search. Each sensing method has distinct strengths and limitations. Based on these findings, the proposed project adopts a single-ESP32 rover architecture in which one controller manages vehicle movement and survivor-detection functions.

The MLX90640 provides low-resolution thermal mapping, while the mmWave sensing channel provides an independent indication of movement. Integrating these functions on a single controller simplifies the hardware architecture and reduces component count while supporting local sensor processing and alert generation.



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The system is intended as a low-cost search aid suitable for staged academic validation, with future scope for improved radar ranging, acoustic sensing and TinyML-based classification.

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