A Search and Rescue Robot for Under Rubble Victim Detection Using Thermal and Sensor Based Systems

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In the critical hours following a natural disaster, achieving a rapid situational assessment is required for the search and rescue operations carried out after natural disasters, especially in collapsed structures. The proposed robotic system provides simultaneous location determination and mapping (SLAM), it uses the robot operating system (ROS2) as a monitoring system for detecting victim signatures. Additionally, it facilitates durability with its robotic platform and track-type system.
Within our integrated design, we combined 2D LiDAR and an MLX90640 thermal sensor using a fusion strategy. This allows the robot to perform spatial mapping while simultaneously detecting survivors by analyzing temperature differentials in its surroundings.
Furthermore, a USB camera was integrated to provide the operator with a real time visual perspective. Data from all integrated sensors, alongside mechanical motion control, are centralized within the RViz2 framework, offering a unified operational dashboard for comprehensive visualization.
Communication is maintained via a high bandwidth TCP/IP network over a Wi-Fi module, ensuring seamless telemetry and real time sensor data streaming. For humanitarian support, the robot incorporates a walkie-talkie voice link alongside a servo mechanism designed to deliver essential life support supplies to trapped individuals. Experimental evaluations demonstrate that the system's performance in spatial reconstruction and thermal signature detection remains resilient against environmental noise. The integration of ROS2 and RVIZ2 ensures a scalable, modular, and professional framework for modern disaster response initiatives.

Keywords: Search and Rescue Robotics, ROS2, Sensor Fusion, SLAM, Thermal Imaging, Disaster Response.

1 Introduction

Our research is motivated by the critical need for resilient search and rescue (SAR) technologies in the immediate aftermath of seismic disasters. When buildings collapse, the resulting environment often becomes highly unstable and inaccessible for human responders, while the first “golden hours” remain crucial for locating and rescuing survivors. To mitigate these risks, this study proposes a tracked robotic platform designed to navigate high-friction debris fields where conventional wheeled or legged systems frequently experience mobility limitations. [1]

One of the primary challenges in such environments is the loss of reliable sensory perception due to dense dust, low visibility, and the absence of ambient light. Conventional RGB cameras therefore become ineffective in many SAR scenarios. To address this limitation, the proposed system employs a dual layer sensing architecture consisting of a 2D LiDAR sensor for real time Simultaneous Localization and Mapping (SLAM) [2] and an MLX90640 thermal sensor array for detecting human heat signatures [3]. By combining LiDAR-based environmental perception with thermal data analysis, the robot is capable of generating navigable maps while simultaneously identifying potential victims even in visually obscured environments. This integrated sensing approach enhances situational awareness and enables rescue teams to obtain critical information from hazardous areas without requiring direct human intervention.

2 Related Work

Search and rescue robotics has received increasing attention due to its potential to reduce the risks faced by human responders in hazardous post-disaster environments. Mobile robotic systems are particularly valuable in collapsed structures, where unstable debris, narrow passages, and limited accessibility make direct intervention difficult. In this context, Pinto et al. presented a low cost robotic system for search and rescue applications and demonstrated that practical robotic platforms can support disaster response tasks under constrained operational conditions. Their work highlights the importance of compact and affordable robotic solutions for field deployment in emergency scenarios [4].

Thermal imaging has also been widely studied as an effective method for victim detection in disaster environments. Since conventional RGB cameras often fail under smoke, darkness, or dense dust, infrared-based sensing provides a more reliable alternative for identifying human presence through body heat. Adams and Jose investigated the automated detection of trapped victims using thermal imaging and showed that thermal sensing can significantly improve victim localization in visually degraded conditions [5]. Similarly, the report cites the work of Pinto et al., where the MLX90640 sensor was used to detect human bodies based on temperature differences from the surrounding environment, confirming the suitability of thermal sensing for search and rescue robots [4].

In addition to victim detection, mapping and navigation remain essential capabilities for robotic rescue systems. LiDAR-based perception and SLAM methods are widely used for enabling robots to operate in unknown and cluttered environments. Bahraini et al. discussed mobile robot navigation and mapping in unknown environments using SLAM techniques, emphasizing the importance of simultaneous localization and mapping for safe movement and environmental awareness [6]. In parallel, Macenski et al. introduced SLAM Toolbox as a practical framework for real-time SLAM in dynamic robotic applications [7], while ROS2-based visualization and mapping tools such as RViz2 and slam toolbox provide effective infrastructure for implementing and monitoring these processes in practice [8], [9].

However, most existing studies address either victim detection or autonomous navigation separately. In contrast, the proposed system integrates LiDAR based SLAM and thermal sensing within a unified ROS2 framework to support both navigation and victim localization in disaster environments.

3 System Architecture

The core design of our platform focuses on keeping the robot functional even when disaster environments become unpredictable. We decided against a monolithic software structure, opting instead for a decoupled, modular framework. This specific architecture ensures that high bandwidth processes, like 2D spatial mapping, do not starve the primary locomotion control of resources. By separating these layers, we ensure the robot remains responsive to safety and driving commands, even when the main processor is under heavy computational load.

3.1 General Design of the Robot

We chose a tracked chassis primarily because post disaster zones are rarely uniform. Unlike wheels that often lose traction on loose debris or dust, tracks provide the surface area needed to climb obstacles while maintaining longitudinal stability. To improve the overall center of gravity, we housed the batteries and drive electronics within the lower section of the frame. A vertical mast was added to support the 2D LiDAR and the MLX90640 thermal array.

3.2 System Block Diagram

To prevent data bottlenecks, the internal processing network follows a distinct two layer hierarchy. The overall system architecture and the interaction between the hardware components are illustrated in Fig. 1.

The Raspberry Pi 4 runs on an Ubuntu Linux environment and acts as the coordinator for all data intensive operations within the ROS2 Humble framework. It handles the processing of LiDAR point clouds, executes SLAM algorithms for positioning, and interprets the thermal matrix via a Python based pipeline.

L298N Motor Driver our design deliberately avoids an extra microcontroller for driving the motors to prevent unnecessary system bloat. We instead wired the L298N H-Bridge driver straight into the Raspberry Pi's GPIO pins. This setup lets the motor driver handle those high current spikes from the DC motors while converting raw logic into physical torque.

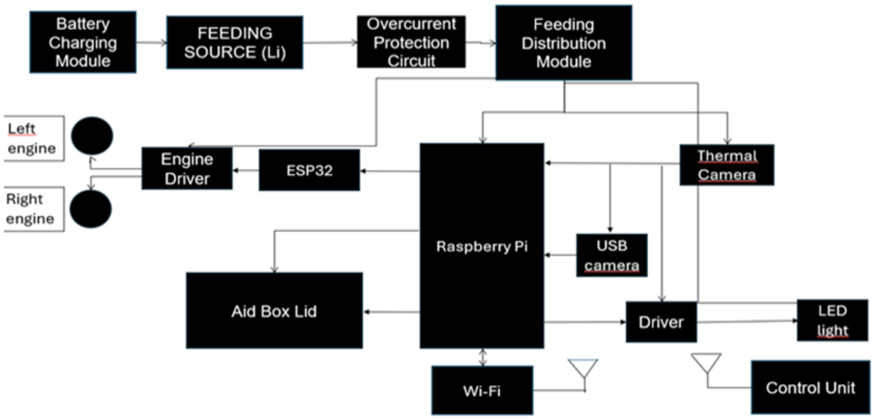

Fig. 1. The integrated hardware architecture of the robotic system.

4 Hardware Design

The robotic platform's physical design focuses on maintaining data integrity while navigating the unpredictable terrain of disaster zones. Instead of relying on a generic assembly, we developed a modular hardware stack, ensuring each peripheral is calibrated for the specific constraints of search and rescue operations.

The internal hardware components of the robotic platform and the Raspberry Pi processing unit used in the system are shown in Fig. 2. and Fig. 3.

4.1 Raspberry Pi Control Unit

A Raspberry Pi 4 serves as the primary compute module, managing high-level navigation while fusing multi modal sensor inputs. To meet the low-latency requirements of search and rescue operations, the unit coordinates real-time communication across all hardware interfaces. System wide synchronization is managed via the ROS 2 (Robot Operating System) framework, which integrates the LiDAR, thermal camera, and motor controllers into a unified data stream. This architecture enables concurrent environmental mapping and victim detection, providing the necessary throughput for complex autonomous tasks.

4.2 MLX90640 Thermal Camera

For survivor detection in low-visibility environments, the system utilizes an MLX90640 thermal sensor [10]. By measuring infrared radiation instead of visible light as conventional RGB cameras do, this unit converts object emissions into temperature based spatial data. In disaster zones where dust, smoke, or total darkness renders visual sensors ineffective, such thermal functionality becomes critical. Operating with a

32×24 pixel array, the sensor provides sufficient resolution to distinguish human body temperatures from the ambient environment. The resulting telemetry is processed via Python based algorithms for heatmap generation, facilitating the extraction of victim coordinates during active search missions.

4.3 LiDAR Integration and SLAM Mapping

Spatial awareness is derived from an RPLIDAR C1 unit, configured for a 360 degree environmental sweep [11]. This scanner feeds high density distance data directly into the SLAM pipeline. Our integration focused on converting raw reflections into 2D occupancy grids in real-time. By utilizing the C1's high sampling frequency, we successfully mapped jagged rubble and thin structural hazards.

4.4 Motor Driver and Mobility System

Navigating unpredictable disaster zones requires the DC motor-driven tracked system utilized by this platform. To manage motion, a driver module translates logic level signals from the Raspberry Pi into the high current electrical outputs necessary for actuation. This tracked configuration ensures superior traversal across uneven or debris laden terrain, offering a distinct mechanical advantage over conventional wheeled platforms. Given the constant variability inherent in disaster environments, such stability remains a fundamental prerequisite for consistent mobility and overall mission success.

4.5 Power Supply and Battery System

System power is supplied by a rechargeable lithium-ion battery pack, specifically rated to sustain the Raspberry Pi, sensing suite, and propulsion mechanism throughout rescue operations. A battery charging module is integrated into the system to allow convenient recharging of the power source.

Power regulation circuits are also included to ensure stable voltage levels for different hardware components. This design helps maintain reliable system performance during long duration operations in field environments.

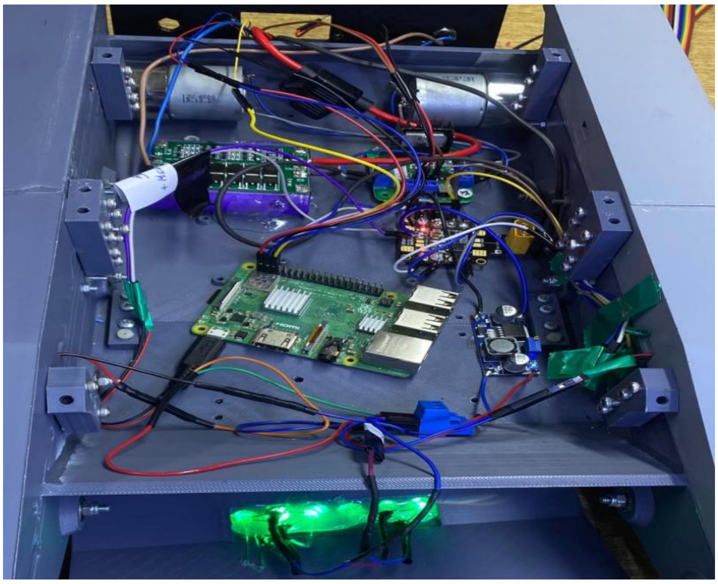

Fig. 2. Internal hardware layout of the proposed search and rescue robot.

Fig. 3. Raspberry Pi processing unit used for sensor data processing.

5 Software Architecture

Designed robotic platform utilizes a decentralized software model to maintain high modularity and operational reliability during rescue missions.

5.1 ROS2 Based System Framework

The core intelligence of the robot is built upon the ROS2 (Robot Operating System 2) [12] Humble distribution running on Ubuntu 22.04 LTS. Instead of a monolithic structure, we adopted a node based architecture where LiDAR processing, thermal imaging, and motor control operate as independent executables. These components communicate via the Data Distribution Service (DDS) layer. This isolated execution model provides a significant fail safe if the thermal processing node encounters a runtime error, the critical navigation and mapping nodes remain active, preventing a total system failure in the field.

5.2 Robot Control via Keyboard Teleoperation

Safe navigation within collapsed structures demands high precision maneuvering, which we addressed by developing a custom teleoperation node. This node captures asynchronous keyboard events and maps them directly to geometry_msgs/Twist message types.

Each discrete keystroke (such as 'W' for forward travel) initiates a publication of specific linear or angular velocity vectors.

Our architecture uses a dedicated subscriber node to intercept these ROS2 topics, converting digital velocity values into pulse width modulation (PWM) duty cycles for the L298N driver. By avoiding excessive software abstraction layers for motor control, we ensured the robot achieves the incremental stepping and torque consistency required to navigate through tight, unpredictable debris gaps.

5.3 Data Communication

Robust telemetry serves as the fundamental link for remote search operations in hazardous zones. The communication between the mobile platform and the ground station relies on a high gain 2.4 GHz WiFi network to bridge the data gap.

We implemented Secure Shell (SSH) for terminal access. SSH protocol allows us to initialize and debug ROS2 nodes on the Raspberry Pi remotely, eliminating the need for a physical monitor on the field. Maintaining a responsive system required us to prioritize latency delivery for critical LiDAR and thermal packets.

6 Victim Detection Method

Victim localization within this framework relies on thermal sensing to overcome the inherent limitations of conventional RGB cameras in disaster zones. Where dust, smoke, or total darkness renders visual data unreliable, the system identifies survivors by isolating human body heat signatures from the ambient environment.

Capturing environmental thermal inputs relies on an MLX90640 sensor operating via a 32×24 pixel array. This configuration maps specific temperature values derived from infrared radiation across the entire grid, enabling the direct transmission of raw telemetry to the Raspberry Pi for immediate processing.

Transforming these temperature gradients into a thermal heatmap improves operational interpretability by isolating regions of high thermal intensity.

6.1 Thermal Image Acquisition

Environmental infrared radiation is captured by the MLX90640 sensor, which converts object emissions into discrete temperature values for transmission to the processing unit via a dedicated communication interface. This unit continuously acquires thermal frames representing the spatial temperature distribution of the observed area to serve as the primary input for the victim detection algorithm.

6.2 Heatmap Generation

Transforming the MLX90640 temperature matrix into a heatmap via Python based processing enhances overall visualization. This mapping assigns color gradients to specific temperature ranges, enabling the isolation of heat signatures from the ambient environment. Such a visual approach remains effective for victim detection even under low contrast conditions, where the thermal gradient between the human body and surrounding debris is minimal.

6.3 Temperature Threshold Detection

Beyond visual heatmap analysis, the system applies a temperature thresholding method to isolate potential human signatures. Since human body temperature typically ranges between 36°C and 37°C, values exceeding a predefined threshold serve as primary indicators of human presence.

The algorithm scans each thermal frame to identify specific regions where detected temperatures surpass this limit. By highlighting these coordinates, the system filters out ambient background noise and focuses operator attention on significant heat sources, thereby enhancing overall detection reliability in complex environments.

The thermal images obtained from the MLX90640 sensor during the victim detection process are shown in Fig. 4. Fig. 5. and Fig. 6.

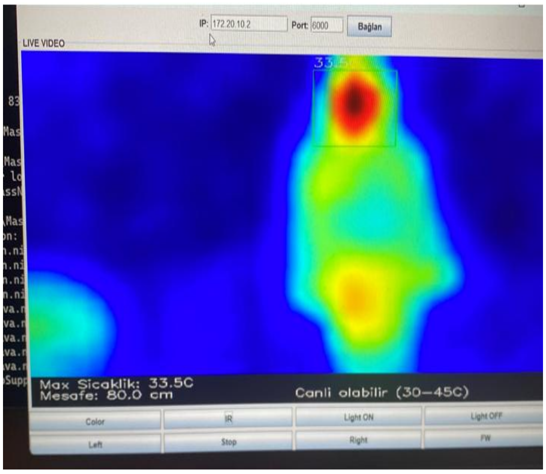

Fig. 4. Detection of a standing human heat signature from a 80.0 cm distance.

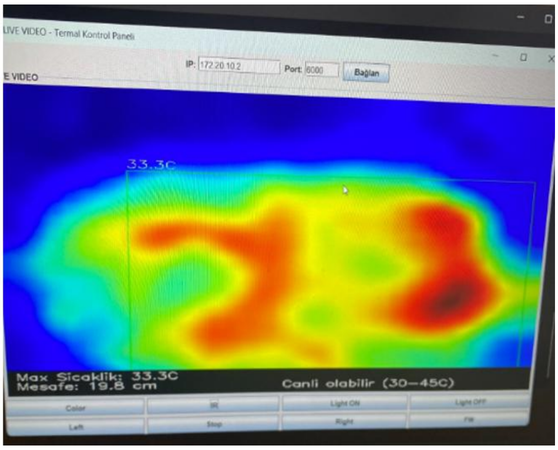

Fig. 5. Detection of a human heat signature beneath a physical cover (obstruction).

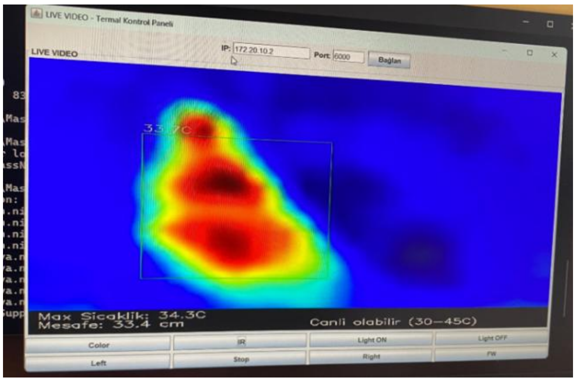

Fig. 6. Detection of a small living target (bird) through a wire mesh (cage).

7 Mapping and Navigation

Robot builds spatial awareness through a multi staged processing pipeline, designed specifically for the unpredictable layouts of disaster zones.

7.1 LiDAR Based Environment Scanning

We handled environment detection using a 2D LiDAR sensor that performs 360 degree scans at high frequency. This unit calculates distances by emitting laser pulses, which then bounce off debris and walls.

A major challenge in collapsed sites is dust or reflective surfaces causing "ghost" readings. To fix this, we added a filtering layer that cleans the data before it reaches the mapping algorithm, ensuring we only map solid structures.

The LiDAR-based environmental map generated during the experiment is shown in Fig. 7.

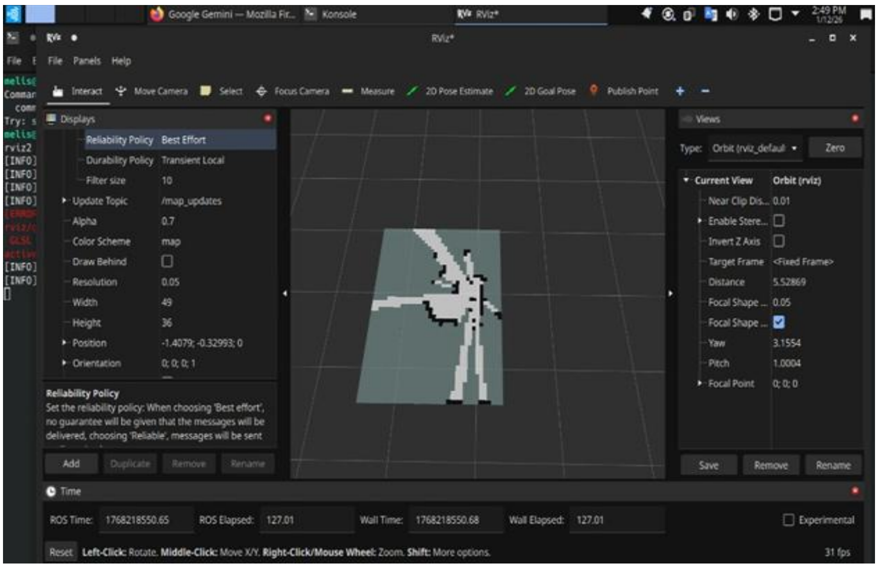

Fig. 7. 2D Occupancy Grid Map generated in real-time by the developed robotic platform within the simulated search and rescue environment using ROS2 and LiDAR sensor.

7.2 SLAM Mapping

Since the robot starts in a completely unknown area, it has to use SLAM (Simultaneous Localization and Mapping). This allows the platform to track its own movement while sketching out the environment.
Our approach uses LiDAR based SLAM to compare one scan to the next, estimating how far the robot has traveled. This process results in an Occupancy Grid Map. The map marks cells as "free", "occupied", or "unknown". For the operator, this grid is the only way to find a safe path through rubble without seeing the robot physically.

7.3 RViz2 Visualization

RViz2 (ROS Visualization) to bring all this data together for the operator. It acts as a digital twin of the search site. The RViz2 interface merges the LiDAR points, the SLAM map, and the robot's exact positioninto a single 3D view.

The real advantage here is overlaying the thermal hotspots (from Section 6) onto this map. This lets the team see exactly where a victim is located relative to the robot's coordinates, which is a life saving feature in time critical missions.

8 Experimental Results

This section presents the experimental evaluation of the proposed search and rescue robotic system. Several tests were conducted to evaluate the performance of the thermal detection mechanism, LiDAR based mapping, and the mobility of the robot in debris like environments. The experiments were performed in a controlled indoor environment to simulate typical search and rescue conditions.

The final experimental result of the robotic system is illustrated in Fig. 8. and Fig. 9.

8.1 Thermal Detection Results

The thermal detection capability of the system was evaluated using the MLX90640 thermal sensor. The sensor continuously captured temperature data from the surrounding environment and transmitted the thermal frames to the Raspberry Pi for processing.

During the experiment, a human subject was positioned at different distances from the robot to observe the sensor's ability to detect body heat. The thermal data was converted into heatmap representations and processed using a temperature thresholding algorithm.

The results showed that the system was able to successfully identify human heat signatures within the detection range of the thermal sensor. Regions exceeding the predefined temperature threshold were highlighted as potential victim locations.

8.2 LiDAR Mapping Results

To properly assess how the robot handles spatial reconstruction, we put the RPLIDAR C1 sensor to the test by scanning complex environments while the platform was in active motion. Instead of just gathering raw distance data, we fed these LiDAR streams into our ROS 2-based SLAM algorithm to generate a reliable occupancy grid map on the fly. During these runs, we specifically looked at how well the system could define sharp boundaries and obstacles in cluttered, debris-like settings.

Monitored the entire mapping progression through RViz2, which acted as our primary visualization hub for tracking both the robot's odometry and the surrounding structural layout. The resulting maps weren't just static images; they provided a precise representation of the environment that allowed the robot to navigate without collisions.

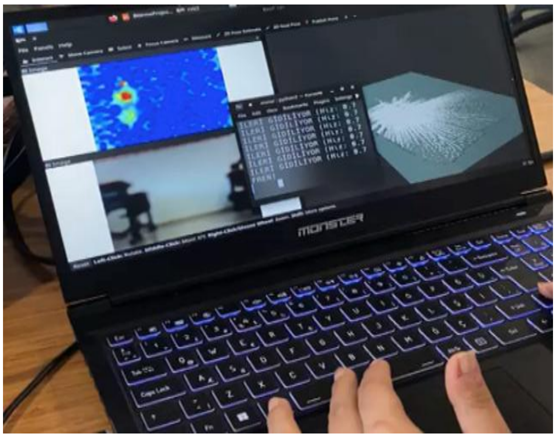

Fig. 8. Visualization obtained during the experimental operation of the robotic system.

Fig. 9. Prototype of the proposed tracked search and rescue robot.

9 Discussion

Field tests involving the developed robot platform confirm that integrating multi modal sensing is vital for urban search and rescue. Our results highlight three primary areas: detection accuracy, navigation efficiency, and communication stability.

The decision to pair the MLX90640 thermal sensor with RPLIDAR C1 distance data proved effective. In disaster zones, thermal imaging alone often triggers false positives due to heated debris or electronics. However, by cross-referencing heat signatures with 2D LiDAR depth data, we achieved more reliable victim identification. The 8–14 µm sensing range successfully distinguished human body temperatures from the ambient environment, even in low visibility setups.

Using the ROS2 slam_toolbox, the system generated stable 2D occupancy grids that clearly defined structural walls and obstacles. The track type chassis provided a clear advantage over wheeled designs, maintaining traction on the jagged rubble typically found in collapsed structures. While airborne dust remains a challenge for optical sensors, our optimized point-cloud filtering minimized "ghosting" effects, allowing the navigation stack to plan viable paths through narrow gaps.

Communication reliability is a known bottleneck in reinforced concrete environments. The 433 MHz RF link used here offered more consistent command transmission than standard Wi-Fi. Furthermore, the two-way voice system served as a critical psychological tool, enabling immediate contact with survivors a feature often missing in purely autonomous prototypes.

10 Conclusion

This research details a search and rescue robotic platform engineered to detect victims in hazardous disaster environments. By integrating thermal sensing, LiDAR based SLAM, and a tracked locomotion system, the platform provides critical assistance to rescue teams in locating survivors within high risk zones.

Technical coordination is managed via a Raspberry Pi within the ROS2 framework, synchronizing heat signature detection from the MLX90640 sensor with environmental perception from the RPLIDAR. Validation of the system’s capacity for simultaneous heatmap generation, mapping, and traversal of uneven terrain was achieved through experimental trials. These results validate the proposed architecture’s ability to enhance situational awareness in restricted or hazardous zones. Ongoing work focuses on sharpening detection accuracy and expanding autonomous navigation to ensure reliability during disaster deployments.

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