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ResQHeart — Non-Contact Life Detection System in Disaster Scenarios

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Abstract—**This paper introduces ResQHeart, an innovative non-contact life detection system designed to rapidly identify individuals trapped under debris or rubble during disasters like earthquakes and building collapses. ResQHeart integrates Microwave Doppler Radar, Thermal sensors, and CO2 sensors to detect vital signs such as movement, body heat, and CO2 levels with precision. Powered by a Raspberry Pi micro-computer (RPI4B), the system processes sensor data seamlessly using Python programming. ResQHeart's intuitive interface empowers rescue teams to visualize real-time data effortlessly, facilitating prompt decision-making. By addressing all aspects of disaster response, ResQHeart emerges as a comprehensive tool for locating people in emergencies, ultimately saving lives.**

Index Terms—**non-contact life detection, microwave doppler radar, Thermal sensor, CO2 sensor, Raspberry Pi, Python-IDE**

I. Introduction

ResQHeart is a system aimed at swiftly locating people trapped beneath rubble during emergencies such as building collapses and earthquakes. It uses specialized sensors capable of detecting movement, heat, and carbon dioxide, making rescue operations more efficient and precise.

This is in response to the growing occurrences and severity of natural/man-made disasters, which often leave people trapped and in urgent need of assistance. Traditional methods of locating individuals under debris tends to be slow. ResQHeart addresses this challenge by providing a faster and more reliable solution. By enhancing emergency responses, it aims to save more lives and make disaster recovery more effective.

The objective of this project is to develop and validate the ResQHeart system, which integrates Microwave Doppler Radar, Thermal sensors, and CO2 sensors, to enhance the efficiency and accuracy of life detection in disaster scenarios. By leveraging these advanced technologies, the system aims to provide reliable and real-time data to support rescue operations.

II. Principle of Operation

ResQHeart functions by emitting a radio wave into the disaster-stricken area, as depicted in "Fig. 1.". This wave penetrates into the debris up to 2m interacts and when it encounters a trapped victim, the system receives an altered signal, enabling the identification and location of trapped individuals. This non-contact life detection principle facilitates rapid and effective search and rescue operations during disasters.

Fig. 1. Principle of Operation

The system is meticulously calibrated to account for environmental variations in temperature, humidity, and CO2 levels. Thermal sensors undergo baseline temperature calibration to establish accurate readings, while CO2 sensors are periodically calibrated to adjust for ambient CO2 levels. Microwave Doppler Radar is calibrated to mitigate background noise and disturbances using advanced signal processing algorithms.

Validation of the system's accuracy and reliability is conducted through rigorous methodologies. Known targets, such as mannequins equipped with heaters, provide controlled scenarios for sensor calibration. Real-world deployments in search and rescue exercises offer valuable feedback for refining the system's performance. Regular calibration routines ensure sensor accuracy over time, and performance metrics provide quantitative measures of reliability.

The integration of Thermal and CO2 sensors with Microwave Doppler Radar significantly enhances the system's accuracy and reliability. Thermal sensors identify the infrared radiation generated by human bodies, which complements Radar data and assists in detecting heat signatures. CO_2 sensors continuously monitor air quality, verifying Radar's detection of micro-movements and providing long-term confirmation of life signs. The redundancy from multiple sensors ensures continuous detection, compensating for individual limitations and providing a comprehensive assessment of the situation.

III. System Model Overview

The ResQHeart model utilizes two separate connection methods for sensor integration with the upper enclosure housing the Raspberry Pi (RPi), display screen, and power supply. A fixed pipe is attached to one side of the upper enclosure which serves as a mounting point for the microwave Doppler radar housed in a separate lower enclosure. The other side of the upper enclosure has a connection point for a probe, which will be flexible, as depicted in "Fig. 2.". This probe connects to a smaller enclosure containing the thermal sensor and CO2 sensor. The flexibility of the probe allows for its insertion into cracks and crevices of rubble or debris piles, enhancing the system's ability to detect trapped individuals.

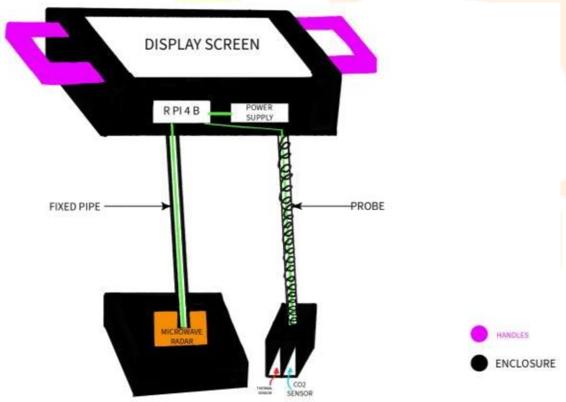

Fig. 2. System Model Overview

IV. Literature Review

After an earthquake, many lives are tragically lost. This occurred in the destruction of the World Trade Centre in New York City, where over 5000 individuals lost their lives. It is believed that the number of casualties may have been reduced with quicker rescue attempts. These catastrophes cause landslides, collapsed tunnels, and avalanches in addition to earthquake damage. A microwave life system for detection that uses the L-band frequency to find people trapped under debris has been created to help with search and rescue efforts. This technology detects variations in breathing and heart rate using the Doppler frequency shift theory. A schematic diagram of the microwave Transmitting/Receiving (T/R) and clutter cancellation subsystem is included in the paper, along with details on different parts such the splitter, directional coupler, and antenna. The adoption of such an approach has the potential to lower earthquake-related deaths globally (Miss Zade Gauri, 2011).

Non-contact vital sign monitoring systems have been receiving considerable attention in the past few years, particularly in emergency, disaster, and security scenarios. But most of the devices in the market today rely on specialized active systems to send high-bandwidth signals. This research presents a passive Wi-Fi radar-based real-time phase extraction approach to identify breathing-related chest movements. Rather of using the conventional range-Doppler processing, this method concentrates on phase variation due to the modest Doppler shift and low amplitude of the movements being observed. Time domain cross correlation is used in the method, and a Hampel filter is included for outlier identification and elimination. The initial section of the study introduces the foundational passive Wi-Fi model and discusses the challenges of using the conventional cross ambiguity function for life detection. Following this, the phase extraction technique is explained in detail, accompanied by an analysis and experimental results. Utilizing data transfers and Wi-Fi beacons, the system is capable of detecting breathing in both through-wall and in-room scenarios. The first-ever use of phase extraction in passive radar for live signal identification has expanded the systems' possible uses (Qingchao Chen, 2016).

The main goal of this endeavor is to identify human motions using UWB radar without making physical touch. Specifically, the focus is on recognizing respiratory patterns in order to locate stationary subjects behind walls. In addition to a Doppler-based method, an innovative approach that employs the short-time Fourier transform is used to detect breathing movements. In a number of measurements, clutter is also decreased by using singular value decomposition (Sridevi. T 2022).

When a natural disaster strikes, the equipment needed to properly identify people trapped behind a lot of debris is usually expensive, specialized, and requires expert operators. It may also not always be available. In order to overcome logistical issues in catastrophe scenarios and expedite rescue efforts, this article investigates the feasibility of utilizing cell phones that have software designed to detect live signs. Experiments carried out in labs using Doppler radar operating at a 2.4 GHz frequency, which is comparable to that of smartphones, demonstrated encouraging results in recognizing human vital signs properly in non-contact identification of people trapped beneath debris. The trials also mimicked psychogenic tremors that might happen when using sensor-equipped devices during a crisis. The wavelength of blood vessel and lung activity was shown to be correlated with the distance between the confined person and the sensor in various scenarios. The article also outlines the development of a pseudo learning algorithm for model-based anomaly recognition in time series, which recognizes vital signs during both irregular and normal breathing. The method is based on medical records and datasets. This study makes a significant contribution to our comprehension of quick rescue actions in emergency scenarios (Linh Pham 2022).

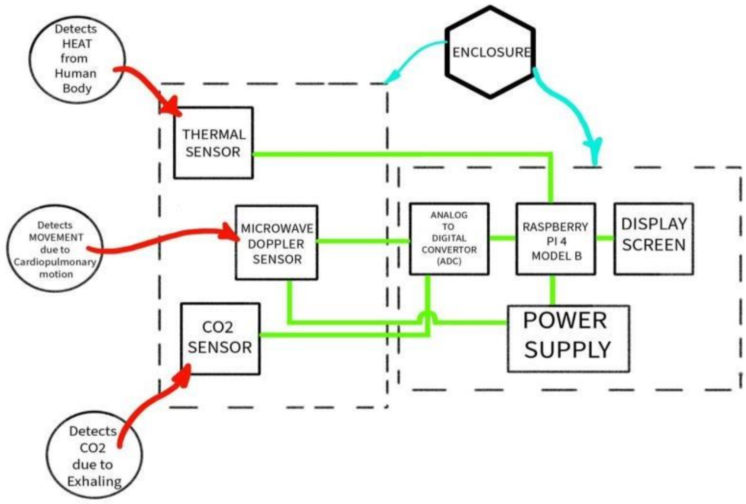

Fig. 3. Block Diagram

V. Hardware Utilized

ResQHeart uses a combination of sensors to detect the presence of life under rubble/debris.

The specific hardware used in the project are:

1. Microwave Doppler Radar
2. Thermal Sensor
3. CO2 Sensor
4. Raspberry Pi
5. ADC
6. Display Screen
7. Power Supply

A detailed Block Diagram outlining the connections among these components is presented in “Fig. 3.”.

1. Microwave Doppler Radar

The Microwave Doppler Radar is responsible for emitting microwave signals, receiving reflected signals and detecting doppler shifts caused by the cardiopulmonary movement of an individual trapped under debris.

It is made up of the following circuits as shown in “Fig. 4.”:

a. Local Oscillator (LO)
b. RF Amplifiers
c. Transmitter and Receiver
d. Mixer
e. Low Pass Filter (LPF)
f. Amplifier

The Local Oscillator (LO) generates a frequency which is the input to the RF Amplifier (the transmitter side), this is then transmitted using an antenna. The Receiver Antenna receives the reflected signal which is doppler shifted (0.2 to 3Hz) due to human cardiopulmonary motion. This signal is very weak and hence needs to be amplified. This is achieved using another RF amplifier (the receiver side).

The signal is further passed through a mixer that combines the LO signal with the amplified signal. Only the Doppler-shifted frequencies are allowed to pass through an LPF after the mixing process. This filtered signal is then further amplified.

The amplified Doppler-shifted signal, which is the microwave Doppler radar system's final output, is sent to the Raspberry Pi via ADC to provide motion information within its coverage area.

The ResQHeart system's Microwave Doppler Radar typically functions within a spectrum spanning from 750 MHz to 4.4 GHz. This range encompasses several common bands used for such applications, including:

L-Band (1-2 GHz): Provides a good balance between range and resolution, making it suitable for detecting movement and micro-movements through debris.

S-Band (2-4 GHz): Frequently used in radar applications due to its ability to balance resolution and penetration through obstacles.

Based on the literature survey, a frequency of around 1150 MHz has been identified as particularly effective for rubble penetration (Miss Zade Gauri, 2011).

This technology is an essential component of the system since it provides a number of distinct benefits:

Penetration Capability: Microwave Doppler Radar can penetrate various non-metallic materials such as rubble, debris, and walls, allowing it to detect life signs that may not be visible or accessible by other means. This capability is crucial in disaster scenarios where visibility and accessibility are often compromised.

Sensitivity to Minute Movements: The minute pulsations of a heartbeat and the mild motions of the chest caused due to respiration are both extremely detectable to this radar. This sensitivity enables it to detect life signs even in scenarios where victims are unconscious or unable to move significantly.

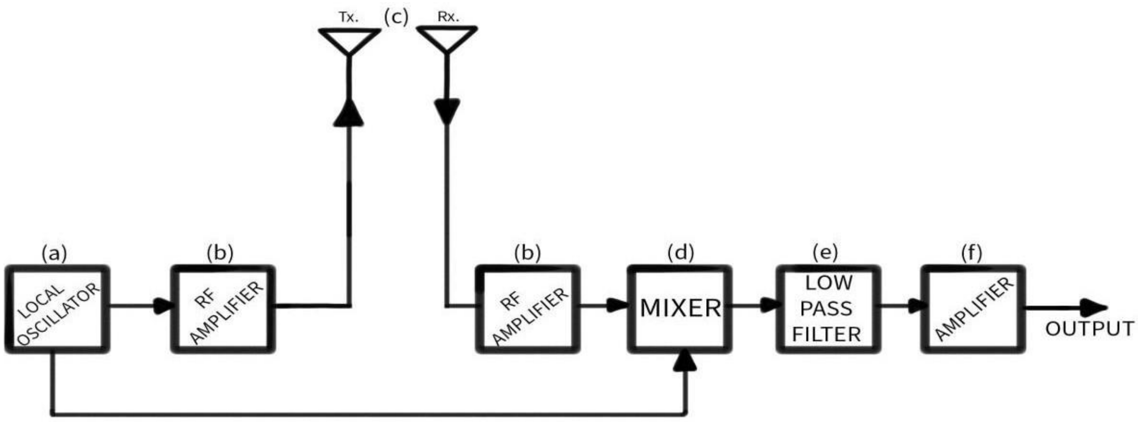

Fig. 4. Microwave Doppler Radar

Discrimination Capabilities: The radar can discriminate between human life signs and other motions, including those from animals or shifting debris, by using advanced signal processing techniques to filter out noise. This reduces false positives and helps rescuers focus on genuine signs of life.

Real-Time Data Acquisition: Microwave Doppler Radar provides real-time data, offering immediate feedback to rescuers for quick assessment and decision-making. This feature is particularly crucial in emergency situations.

2. Thermal Sensor

The MLX90640 IR Array Thermal Imaging Camera shown in "Fig. 5." integrates a thermal camera which generates thermal images. Communication with the camera is done via I2C.

The specifications of the Thermal Sensor are detailed in "Table I.".

TABLE I: SPECIFICATION OF MLX90640 IR ARRAY THERMAL IMAGING CAMERA

Specification	Value
Operating Voltage	3V-3.6V
Current Consumption	18mA
Field of View	55°x 35°
Measurement Range	-40°C-300°C
Resolution	±1.5°C
Refresh Rate	0.5Hz-64Hz

Differentiating between live humans and other heat sources using thermal sensor data is a critical function of the ResQHeart system. This differentiation is achieved through several advanced techniques and algorithms:

Temperature Range Filtering:

- Human Body Temperature Range: The system filters heat sources based on the typical human body temperature range (approximately 36°C to 37°C or 96.8°F to 98.6°F). Non-human heat sources often fall outside this range, allowing the system to focus on potential human signatures.

Thermal Signature Analysis:

- Shape and Size Detection: Humans have a distinct thermal shape and size, which can be identified by the thermal camera. Algorithms distinguish the human body from other objects by identifying its distinctive shape.

Fig. 5. MLX90640 Thermal Imaging Camera

3. CO_2 Sensor

The MG811 CO_2 Sensor shown in "Fig. 6." employs Metal Oxide Sensor Technology, which requires heating the sensor to a specified level to initiate the separation of CO_2 from the air. The sensor gives precise readings of CO_2 concentration levels by calculating the quantity of infrared (IR) radiation received by carbon dioxide molecules.

The specifications of the CO2 Sensor are detailed in "Table II.".

TABLE II: SPECIFICATION OF MG811 CO_2 SENSOR

Specification	Value
Operating Voltage	6V DC
Detection Zone	0 – 10000 ppm

Distinguishing between human respiration and other CO_2 sources, such as decaying organic matter, presents a challenge for CO_2 sensors alone. However, the ResQHeart system employs several strategies to enhance the specificity of CO_2 detection for identifying human respiration:

Multi-Sensor Integration:

- Combined Sensor Data: Integrating CO2 sensor data with thermal and microwave Doppler radar sensors helps differentiate human respiration. For instance, a detected increase in CO2 concentration, coupled with thermal signatures of body heat and micro-movements from radar, strongly indicates human presence.

Temporal Patterns:

- Breathing Patterns: Human respiration produces a rhythmic, regular pattern of CO2 emissions. By analyzing these temporal patterns, the system can distinguish between the continuous emissions from decaying organic matter and the periodic peaks of human breaths.

Concentration Levels:

- Localized Concentration Peaks: Human respiration typically results in localized and transient peaks in CO_2 concentration, whereas decaying organic matter tends to produce more diffuse and steady increases. Focusing on sharp, periodic peaks helps identify human respiration.

Environmental Context and Analysis:

- Contextual Filtering: The system considers the environmental context where the sensor is deployed. For instance, in the case of a collapsed structure, areas that were previously known to be occupied—such as living quarters and offices—are given priority when it comes to identifying human presence.

Mitigation Example:

- Scenario: In a collapsed building, CO_2 sensors detect elevated CO_2 levels.
- Combined Data: Thermal sensors identify heat sources, and microwave Doppler radar detects micro-movements consistent with human breathing.
- Pattern Analysis: The system analyzes CO_2 concentration for periodic peaks corresponding to breathing patterns.
- Machine Learning: An AI model cross-references the detected patterns with trained data, confirming the likelihood of human respiration.

By utilizing these methods, the ResQHeart system enhances the specificity of CO_2 sensors in detecting human respiration and differentiating it from other sources of CO_2 like decaying organic matter.

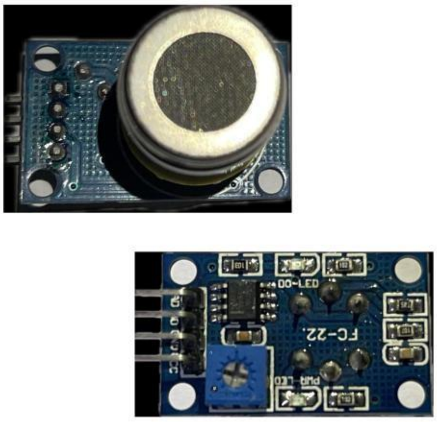

Fig. 6. MG811 CO_2 Sensor

4. Raspberry Pi

The Model B version of the Raspberry Pi 4 as shown in “Fig. 7.” is a compact yet powerful single-board microcomputer with a Quad-Core 64-bit processor, up to 4GB of RAM, and a number of connectivity choices, including 4 USB ports, two micro-HDMI outputs, and 28 BCM2711 GPIOs accessible via the standard Raspberry Pi 40-pin header.

For additional specifications of the RPi4B, please refer “Table III.”.

The Raspberry Pi will handle the processing of all sensor data within the project domain.

TABLE III: SPECIFICATION OF RASPBERRY PI 4 MODEL B

Feature	Description
Clock Speed	1.5 GHz
Networking	Gigabit Ethernet, 802.11 b/g/n/ac Wi-Fi
Bluetooth	Bluetooth 5.0
Storage	microSD card slot
Power	USB-C power supply
Operating Temperature	0°C to 50°C

The Raspberry Pi (RPi) utilized in the hardware setup of the ResQHeart system possesses several key features that make it an ideal choice for this application:

Processing Power:

- Quad-core Processor: The latest models, such as the Raspberry Pi 4, boast a quad-core ARM Cortex-A72 CPU, 64-bit SoC, clocked at 1.5 GHz, providing ample computational power to handle complex algorithms and data processing from multiple sensors.
- Memory: Smooth multitasking and effective data management are made possible by the Raspberry Pi's 2GB to 8GB RAM choices.

Operating System and Software:

- Raspberry Pi OS: This lightweight and robust operating system, optimized for the Raspberry Pi platform, offers a user-friendly interface and extensive software support.
- Support for Multiple Programming Languages: The Raspberry Pi supports various programming languages, including Python, C/C++, and more, facilitating the development of custom applications for sensor data integration and processing.
- Libraries and Tools: Access to a plethora of libraries and development tools, such as OpenCV for image processing and scientific/engineering libraries for data analysis, further enhances its versatility.

Form Factor and Expansion:

- Compact Size: The Raspberry Pi's small and lightweight design facilitates its incorporation into portable systems, making it suitable for deployment in disaster scenarios.
- Expansion Options: Compatibility with HATs (Hardware Attached on Top) and other expansion boards enables the addition of functionalities like GPS modules, additional sensors, or extended I/O capabilities.

Community and Support:

- Extensive Community Support: The Raspberry Pi benefits from a large and active community that provides abundant tutorials, forums, and resources for troubleshooting and development.
- Wide Range of Accessories: Availability of numerous accessories,

including cases, power supplies, and display modules, facilitates customization and enhances usability.

These features, coupled with libraries like NumPy, SciPy, and Matplotlib for signal processing, make the Raspberry Pi an excellent choice for the ResQHeart system. Its computational power, flexibility, and connectivity enable effective integration and processing of data from the Microwave Doppler Radar, thermal camera, and CO2 sensors, ultimately enhancing the system's ability to accurately and reliably detect humans buried under debris during search and rescue operations.

In terms of handling the real-time processing demands:

GPU:

- The VideoCore VI GPU can assist with rendering visual data, potentially offloading some tasks from the CPU.

Data Acquisition:

- Microwave Doppler Radar: Continuous stream of high-frequency data requiring real-time signal processing to detect motion and micro-movements.
- CO2 Sensors: Periodic sampling of CO2 concentration levels, less demanding than radar in terms of data rate.
- Thermal Camera: High-resolution thermal imaging data requiring processing to generate heatmaps and identify thermal signatures.

Data Processing:

- Signal Processing: For radar data, real-time FFT (Fast Fourier Transform) or other signal processing techniques are needed to detect motion and breathing patterns.
- Pattern Recognition: Machine learning models or pattern recognition algorithms to differentiate between human signatures and other sources.
- Data Fusion: Combining information from various sensors to create a coherent picture and cross-verify detections.

Visualization:

- Real-time rendering of thermal heatmaps and radar detection overlays.
- User interface updates for displaying sensor readings and alerts.

While the RPi4 is powerful enough to handle many real-time processing tasks simultaneously, the efficiency of the software and the specific demands of the application will determine its overall performance. Careful optimization, efficient coding, and strategic load distribution are key to ensuring it meets the real-time processing demands of the ResQHeart system.

Fig. 7. Raspberry Pi 4 Model B

5. ADC (ANALOG to DIGITAL CONVERTER)

In the ResQHeart project, the ADS1115 16-Bit ADC shown in “Fig. 8.” converts analog sensor data with precision. Its 16-bit resolution and programmable gain amplifier ensure accurate measurement of critical signals. With compatibility across a wide voltage range (2V to 5V) and a compact design, integration into the system is simplified.

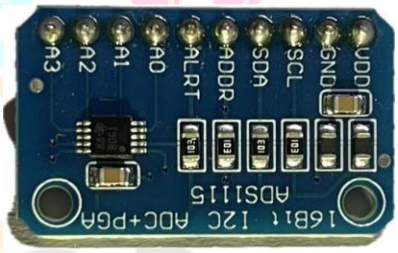

Fig. 8. ADS1115 ADC

6. Display Screen

The REES52 Raspberry Pi 7 Inch Capacitive Touch Screen LCD integrates seamlessly into the ResQHeart system, offering a high-definition display and responsive touch screen interface. This display (“Fig. 9.”) provides real-time access to sensor data, facilitating swift decision-making during emergencies, while its intuitive touch functionality enhances usability.

The user interface (UI) of the ResQHeart system is instrumental in aiding rescue teams to make quick and informed decisions during disaster scenarios. By presenting real-time data from multiple sensors (thermal, radar, and CO2) in a clear and efficient manner, the UI significantly enhances the effectiveness of rescue operations.

Real-Time Data Visualization significantly enhances the effectiveness of rescue teams during disaster scenarios by providing immediate, clear, and actionable information. Here are the key benefits of this feature for rescue operations:

- Quick Assessment:
  Real-time visualization enables rescue teams to quickly assess the situation by providing immediate feedback on the location and status of survivors. This capability helps teams prioritize their efforts and allocate resources efficiently.
- Enhanced Decision-Making:
  Visualizing data from multiple sensors (radar, thermal, and CO2) in real-time allows teams to make informed decisions. By presenting a

comprehensive picture of the environment and the condition of potential survivors, teams can plan and execute their operations more effectively.

- Continuous Monitoring:
  Real-time visualization supports continuous monitoring of the disaster site. This ongoing assessment helps teams track the progress of rescue operations and make necessary adjustments as new data becomes available.
- Dynamic Response:
  As new information is visualized, rescue teams can dynamically adapt their strategies. For instance, if a new heat signature or movement is detected, teams can immediately redirect their efforts to the new location, ensuring a swift response to changing conditions.

The user interface (UI) of the ResQHeart prioritizes clarity and efficiency, ensuring that rescue teams can quickly interpret the data from each sensor and make informed decisions. Here's a detailed breakdown of how data from the thermal, radar, and CO2 sensors is presented:

Thermal Sensor Data:

- Heatmap Visualization: The thermal sensor data is displayed as a color-coded heatmap, helping in quickly identifying areas of interest where humans might be located.

Microwave Doppler Radar Data:

- Movement Detection Graphs: Radar data is visualized through movement detection graphs that show the presence and intensity of motion, aiding in identifying subtle movements that might be missed by other sensors.
- Live Motion Indicators: Real-time indicators, such as blinking dots or icons, are used to mark areas where movement is detected, providing a visual cue to rescuers about potential locations of survivors.
- Micro-Movement Analysis: Detailed analysis windows show patterns of micro-movements, helping to differentiate between human activity and other types of movement.

CO2 Sensor Data:

- Concentration Levels: The CO2 sensor data is displayed as numerical readings indicating the concentration of CO2 in parts per million (ppm), allowing rescuers to monitor air quality and detect areas with elevated CO2 levels, which can indicate human presence.

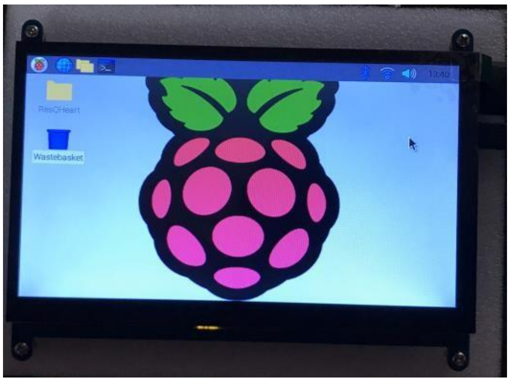

Fig. 9. Display Screen

VI. SOFTWARE UTILIZED

In the ResQHeart project, Python is the primary software framework, leveraging its versatile and user-friendly nature. Utilizing Python, along with essential libraries and frameworks, facilitates efficient data processing, sensor integration, and system management on Raspberry Pi platforms. This approach enables rapid development, seamless hardware integration, and robust performance in real-time life detection scenarios.

The ResQHeart system leverages Python for several critical tasks, enhancing both its functionality and efficiency. The use of Python provides numerous benefits, making it an ideal choice for the development and operation of the system.

Key aspects include:

Ease of Use and Rapid Development:

- Python's straightforward syntax and readability facilitate rapid development and easy maintenance, which is beneficial for prototyping and iterative development.
- A vast ecosystem of libraries and frameworks (e.g., NumPy, SciPy, OpenCV, TensorFlow) can significantly accelerate development, providing pre-built functions for data processing, machine learning, and sensor integration.

Challenges with Python for Real-Time Processing:

- Performance Overhead: As an interpreted language, Python introduces performance overhead compared to compiled languages like C or C++. Real-time processing tasks might suffer from higher latency and lower throughput, especially for CPU-intensive operations.
- Garbage Collection: Python's automatic garbage collection can introduce unpredictable pauses, which might be problematic for real-time applications where consistent performance is critical.

Mitigation Strategies:

- Performance-optimized libraries such as NumPy and SciPy, which are implemented in C, provide efficient numerical computation capabilities within Python, thereby reducing performance overhead

- GPU Acceleration: Libraries such as PyCUDA or CuPy support GPU-accelerated processing, offloading heavy computations from the CPU to the GPU, that enhances performance.

Python IDE Software Contributions:

- User-Friendly Interface: Python IDEs, such as Thonny, PyCharm, or the built-in IDE in the Raspberry Pi OS, offer intuitive and easy-to-navigate interfaces. This facilitates quick development, testing, and debugging of code, ultimately speeding up the development process and enabling rapid iteration.
- Concurrent Processing: By utilizing libraries such as asyncio or threading, Python can manage concurrent tasks, such as monitoring multiple sensors simultaneously. This capability enhances the system's responsiveness and reliability, enabling it to handle complex tasks efficiently.

VII. Power Consumption of the System

To determine the power consumption of the ResQHeart system and its operating duration on a single battery charge, we analyze the power requirements of each component and calculate the total power consumption and operating time as follows:

- Determine the Power Consumption for Each Component:
  Raspberry Pi 4: The average power consumption is 5 watts.
  Microwave Doppler Radar: Typically consumes around 1-2 watts. We'll assume 1.5 watts for this calculation.
  CO2 Sensor: Typically consumes around 0.1-0.2 watts. We'll assume 0.15 watts for this calculation.
  Thermal Camera: Typically consumes around 1-2 watts. We'll assume 1.5 watts for this calculation.
- Calculate the Total Power Consumption:
  Sum the power consumption of all components:

$$\textit{Total Power Consumption} = 5W + 1.5W + 0.15W + 1.5W = 8.15W \quad (1)$$

- Determine the Battery Capacity:
  The battery is specified as 5V, 3A.
  Battery capacity in Watt-Hours (Wh):

$$\textit{Battery Capacity}\ (Wh) = 5V \times 3A = 15Wh \quad (2)$$

- Calculate the Operating Time:
  Divide the battery capacity by the total power consumption:

$$\text{Operating Time(hours)} = \frac{\text{Battery Capacity(Wh)}}{\text{Total Power Consumption(W)}} = \frac{15\text{Wh}}{8.15\text{W}} \approx 1.84 \text{ hours} \quad (3)$$

Therefore, the ResQHeart system, including the Raspberry Pi 4, microwave Doppler radar, CO2 sensor, and thermal camera, can operate for approximately 1.84 hours on a single battery charge.

VIII. Challenges, Limitations and Mitigation Strategies

Challenges Faced during Development and Integration:

High-Frequency Generation for Radar Sensor:

- Challenge: Producing stable and accurate high-frequency signals for the Microwave Doppler Radar was technically challenging, requiring precision electronic components and design.
- Solution: We employed a signal generator module capable of generating frequencies from 35M to 4.4GHz, providing the necessary stability and accuracy for high-frequency signal generation.

Calibrating the CO2 Sensor:

- Challenge: Ensuring accurate readings from the CO2 sensor necessitated meticulous calibration, sensitive to environmental factors such as temperature, humidity, and the presence of other gases.
- Solution: We established a routine calibration schedule to recalibrate the sensors periodically, maintaining accuracy. Automated calibration routines using known gas concentrations were employed to streamline this process.

Generating a Live Heatmap with the Thermal Camera:

- Challenge: Creating a live, real-time heatmap from the thermal camera data required efficient processing and visualization techniques.
- Solution: By utilizing optimized libraries like OpenCV and leveraging the processing power of the Raspberry Pi 4, we enabled efficient real-time processing of thermal data, facilitating the creation of a live heatmap.

Addressing Limitations and Mitigation Strategies:

Environmental Interference:

- Limitations: Obstructive debris, adverse weather conditions, and electromagnetic interference can affect sensor performance.
- Mitigation: Advanced signal processing algorithms, strategic sensor placement, and shielding techniques can help mitigate these environmental challenges.

False Positives and Negatives:

- Limitations: Accuracy issues such as false positives and false negatives can mislead rescue efforts.
- Mitigation: Cross-verification using multiple sensors and regular calibration and testing can help minimize the chances of errors.

These challenges, limitations, and mitigation strategies were crucial aspects of the development and integration process of the ResQHeart system, ensuring its effectiveness and reliability in various disaster scenarios.

IX. Results

"Fig. 10." depicts the output reading of MG811 CO2 Sensor and the interpolated live plot of the MLX90640 IR Thermal Imaging Camera.

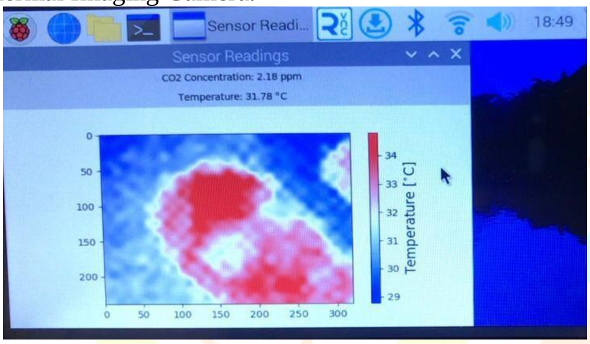

Fig. 10. MG811 CO2 Sensor's Output Reading and the interpolated plot of the MLX90640 IR Thermal Imaging Camera

X. Final Model

"Fig. 11." depicts the final model of the ResQHeart System.

Fig. 11. ResQHeart Final Model

XI. Future Improvements

Several future improvements and additional features could be incorporated into ResQHeart to further enhance its life detection capabilities and overall effectiveness in search and rescue operations. Here are some potential enhancements:

Multi-Spectral Imaging:

- Incorporate Near-Infrared (NIR) and Ultraviolet (UV) Imaging: Adding multi-spectral imaging capabilities can provide additional layers of information about the disaster site, such as detecting chemical residues or uncovering hidden objects.

Integration with IoT and Cloud Services:

- IoT Integration: Integrate with IoT devices and sensors deployed in smart buildings and infrastructure to enhance situational awareness and improve response coordination.
- Cloud-Based Data Analytics: Utilize cloud-based data analytics platforms to process and analyze large volumes of sensor data more efficiently, enabling real-time decision-making and predictive analytics.

Autonomous Robotic Systems:

- Autonomous Search Robots: Design and deploy autonomous robotic systems equipped with sensors to navigate and explore hazardous areas autonomously, enhancing coverage and efficiency.
- Robotic Manipulators: Equip robots with robotic manipulators capable of clearing debris and reaching inaccessible areas to assist in rescue operations.

Enhanced Data Fusion and Analysis:

- Machine Learning Algorithms: Develop advanced machine learning algorithms to analyze sensor data and identify patterns associated with human presence more accurately.
- Data Fusion Techniques: Implement sophisticated data fusion techniques to integrate information from multiple sensors seamlessly and extract actionable insights.

Incorporating additional sensors and machine learning algorithms can significantly enhance the life detection capabilities of a rescue system. Here's how these enhancements might be implemented:

Additional sensors:

Microphone Arrays:

- Purpose: To capture sounds such as cries for help, movements, or tapping.
- Benefit: Can enhance the detection of auditory signals from survivors trapped under debris.

Humidity and Temperature Sensors:

- Purpose: To monitor environmental conditions.
- Benefit: Changes in humidity and temperature might indicate the presence of a living person.

Machine Learning Algorithms:

Sound Classification:

- Purpose: To classify sounds captured by microphones as human voices, tapping, or other significant noises.

- Implementation: Using models like Convolutional Neural Networks (CNNs) trained on audio data.
- Benefit: Enhances the ability to detect and respond to auditory signals from survivors.

Anomaly Detection:

- Purpose: To detect unusual patterns or anomalies that might indicate the presence of survivors.
- Implementation: Using algorithms like Isolation Forest or Autoencoders.
- Benefit: Can detect subtle signs of life that might be missed by traditional methods.

XII. CONCLUSION

In conclusion, the ResQHeart project represents a significant advancement in disaster response technology, offering a robust solution for swiftly detecting and locating individuals trapped under debris. By integrating state-of-the-art sensor technologies with the versatile Raspberry Pi microprocessor and Python programming language, the system enables rescue teams to access real-time data essential to facilitate informed decision-making during emergency situations. The comprehensive approach adopted in building the ResQHeart system ensures its effectiveness in critical scenarios, enhancing the efficiency of search and rescue operations and ultimately contributing to saving lives. As we further refine and optimize the ResQHeart system, its potential impact in mitigating the devastating effects of disasters remains promising, emphasizing the critical role of innovation and technology in humanitarian endeavors.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Jeanette Pereira initiated the project, including drafting the manuscript, revising it, creating project presentations, and coding the thermal and CO2 sensor. Anthony Vaz contributed to the project design, performed circuit soldering, and collaborated on the initial coding of the sensors. Shaunak Valvaiker collaborated with Anthony Vaz on designing the microwave Doppler radar and also contributed to coding the thermal and CO2 sensor. Akshara Naik and Sharvari Chanekar provided guidance as project guides, contributed to project supervision, data interpretation, and critically revised the manuscript for important intellectual content. All authors contributed equally to all aspects of the project, including design, experimentation, data analysis, and manuscript preparation. All authors have reviewed and approved the final manuscript.

REFERENCES

[1] Álvarez-Merino CS, Khatib EJ, Luo-Chen HQ, Barco R. 2022. "Victim Detection and Localization in Emergencies." *Sensors (Basel).* doi:https://doi.org/10.3390/s22218433.

[2] Amina Khan, Sumeet Gupta, Sachin Kumar Gupta. 2020. "Multi-hazard disaster studies: Monitoring, detection, recovery, and management, based on emerging technologies and optimal techniques." *International Journal of Disaster Risk Reduction.* doi:https://doi.org/10.1016/j.ijdrr.2020.101642.

[3] Apurva Sadanand Ubhale, Prof. P. N. Pusdekar. 2017. "System to Detect Human Being Buried under the Rubble During Disaster: A Review." *IJARIIE* 3 (1).

[4] B. Valarmathi, Jain Kshitij, Rajpurohit Dimple, N. Srinivasa Gupta, Y. Harold Robinson, G. Arulkumaran and Tadesse Mulu. 2023. "Human Detection and Action Recognition for Search and Rescue in Disasters Using YOLOv3 Algorithm." *Journal of Electrical and Computer Engineering.* doi:https://doi.org/10.1155/2023/5419384.

[5] Choset, Binoy Shah and Howie. 2004. "Survey on Urban Search and Rescue Robotics." *Journal of the Robotics Society of Japan* 582-586.

[6] Di Zhang, Salvatore Sessa, Ritaro Kasai, Sarah Cosentino, Cimarelli Giacomo, Yasuaki Mochida, Hiroya Yamada, Michele Guarnieri, Atsuo Takanishi. 2018. "Evaluation of a Sensor System for Detecting Humans Trapped under Rubble: A Pilot Study." *MDPI sensors.*

[7] Gao, Massey, Selavo, Crawford, Chen, Lorincz, Shnayder, Hauenstein, Dabiri, Jeng, et al.,. 2007. "The advanced health and disaster aid network: A light-weight wireless medical system for triage." *IEEE Trans. Biomed. Circuits Syst* 203-216.

[8] George S.M., Zhou, Chenji, Won M, Lee, Y.O, Pazarloglou, Stoleru, Barooah. 2010. "A wireless ad hoc and sensor network architecture for situation management in disaster response." *IEEE Commun. Mag.* 128-136.

[9] Krerngkamjornkit, Rapee. 2013. "Human Body Detection in Search and Rescue Operation Conducted by Unmanned Aerial Vehicles." *Advanced Materials Research* 1077-1085.

[10] Kun-Mu Chen, Yong Huang, Jianping Zhang and A. Norman. 2000. "Microwave life-detection systems for searching human subjects under earthquake rubble or behind barrier." *IEEE Transactions on Biomedical Engineering.* doi:10.1109/10.817625.

[11] Linh Pham, Manoranjan Paul, Pwc Prasad. 2022. "Noncontact Detection of Cardiopulmonary Activities of Trapped Humans in Rescue Relief Events." *IEEE Access* 10: 75680-75692.

[12] M. Jelen, E. M. Bieble. 2006. "Multi-frequency sensor for remote measurement of breath and heart beat." *Advances in Radio Sci* 79-83.

[13] Miss Zade Gauri, Mr Badnerkar S. S. 2011. "A Modern Microwave Life Detection System for Human Being Buried under Rubble." *International Journal of Advanced Engineering Research and Studies (IJAERS)* I (I): 69-77.

[14] Negra, Jemili, Belghith. 2016. "Wireless Body Area Networks: Applications and Technologies." *Procedia Comput. Sci* 1274-1281.

[15] Preethi, S. Karthikeyan and N. S. Renga. 2018. "Life detection system using UWB Radar During Disaster." *Second International Conference on Green Computing and Internet of Things (ICGCIoT).* Bangalore. 361-365. doi:10.1109/ICGCIoT.2018.8752992.

[16] Qingchao Chen, Kevin Chetty, Karl Woodbridge, Bo Tan. 2016. "Signs of Life Detection Using Wireless Passive Radar." *IEEE Radar Conference.*

[17] S Lourdu Jame, Y Jeyashree, S.Srikantan, P. Jais Duraimani, Mohamed Dhageer. 2019. "Detection of Human Under Earthquake Rubble." *International Journal of Recent Technology and Engineering (IJRTE)* 8 (2S11): 3391-3394.

[18] S.Alagammal, R.Bhavani. 2017. "Detection of Trapped Victims beneath Building Rubble using Microwave Life Detection Systems in X Band." *Trends in Microwave Engineering and Technology, ManTech Publications* 2 (1).

[19] Sajjad Ahmed, Ariffuddin Joret, Norshidah Katiran, Muhammad Suhaimi Sulong. 2022. "Human Detection Techniques for Search and Rescue of Trapped Victims Under Debris: A Review." *Penerbit UTHM* 54-65.

[20] Sang Hoon Oh, SeungBong Lee, Sung Min Kim, Jae Hoon Jeong. 2021. "Development of a heart rate detection algorithm using a non-contact doppler radar via signal elimination." *Biomedical Signal Processing and Control* 64.

[21] Sharifah Mastura Syed Mohd Daud, Mohd Yusmiaidil Putera Mohd Yusof, Chong Chin Heo, Lay See Khoo, Mansharan Kaur

Chainchel Singh, Mohd Shah Mahmood, Hapizah Nawawi. 2022. "Applications of drone in disaster management: A scoping review." *Science & Justice* 30-42. doi:https://doi.org/10.1016/j.scijus.2021.11.002.
[22] Shi, Ding, Fulai Liang, Jiahao Qiao, Yaru Wang, Yidan Zhu, Hao Lv, Xiao Yu, Teng Jiao, Fuyuan Liao, Keding Yan, and et al.,. 2023. "A Novel Non-Contact Detection and Identification Method for the Post-Disaster Compression State of Injured Individuals Using UWB Bio-Radar." *Bioengineering.* doi:https://doi.org/10.3390/bioengineering10080905.
[23] Sridevi. T, Jaswanth Sai. V, Yashaswini. G, Sri Vani Reddy. S, Lokesh. V. 2022. "Ultra Wide Band Radar System for Through Wall Human Vital Signs Detection." *International Research Journal of Engineering and Technology (IRJET)* 09 (06): 1141-1143.
[24] T. Huang, X. Zou, Z. Wang, H. Wu and Q. Wang. 2022. "RGBD image based human detection for electromechanical equipment in underground coal mine." *IEEE International Conference on Mechatronics and Automation (ICMA).* 952-957. doi:10.1109/ICMA54519.2022.9856066.
[25] T. Miller, L. Potter, and J. McCorkle. 1997. "RFI suppression for ultra wideband radar." *IEEE Trans. Aerosp. Electron. Syst.* 1142-1156.
[26] Tian, Bingwei, Wenrui Liu, Haozhou Mo, Wang Li, Yuting Wang, and Basanta Raj Adhikari. 2023. "Detecting the Unseen: Understanding the Mechanisms and Working Principles of Earthquake Sensors." *Sensors.* doi:https://doi.org/10.3390/s23115335.
[27] U. Zakia, M. W. Turza, E. Karim, T. Z. Moumita and T. A. Khan. 2016. "A Navigation system for rescue operation during disaster management using LTE advanced network and WPAN." *IEEE 7th Annual Information Technology, Electronics and Mobile Communication Conference (IEMCON)* 1-6. doi:10.1109/IEMCON.2016.7746280.
[28] Varun, Menon, Priya. 2016. "Ensuring Reliable Communication in Disaster Recovery Operations with Reliable Routing Technique." *Mob. Inf. Syst.* doi:10.1155/2016/9141329.
[29] Yonggu Lee, Jun-Young Park, Yeon-Woo Choi, Hyun-Kyung Park, Seok-Hyun Cho, Sung Ho Cho, Young-Hyo Lim. 2018. "A Novel Non-contact Heart Rate Monitor Using Impulse-Radio Ultra-Wideband (IR-UWB) Radar Technology." *Scientific Reports.*
[30] Zheng Yang, Kazutaka Mitsui, Jianqing Wang, Takashi Saito, Shunsuke Shibata, Hiroyuki Mori, Goro Ueda. 2021. "Non-Contact Heart-Rate Measurement Method Using Both Transmitted Wave Extraction and Wavelet Transform." *MDPI sensors.*

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