

Enhancing Body Detection in CSSR Operations Using Advanced Technology: A Combined RF and Thermal Sensing System for Rural and Mining-Affected Areas

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Abstract: Collapsed buildings, mine roofs and landslides trap people under heavy debris, and their chances of survival fall as time passes. Finding the exact position of a victim is the slowest and riskiest part of collapsed structure search and rescue (CSSR), especially in rural and mining-affected areas where modern equipment, light and stable ground are not available. This paper studies an Advance Body Detection System (ABDS) that sends 1.5 GHz radio-frequency (RF) waves into the debris and uses a low-cost thermal camera to confirm the heat of a human body. The architecture, the RF chain (antenna, VCO, LNA, mixer and analog-to-digital detector), the processing unit and a decision logic that cross-references both sensors are explained with block diagrams, a signal-processing chain and a flowchart, and basic calculations for the RF module and the thermal camera are given. The study, based on recent literature (2020 onwards), shows that RF waves can pass through non-metallic debris and sense the small movement of a hidden person, while a thermal camera detects body heat only at the surface; using both together gives more confident detection than either alone. The main limitations are unwanted reflections from debris, metal and moisture, limited penetration depth, radio-frequency regulations and the need for field trials. No experiments were carried out; calculated values are typical values for explanation.

Keywords: Collapsed structure search and rescue (CSSR), body detection, 1.5 GHz RF sensing, thermal imaging, Advance Body Detection System (ABDS), Raspberry Pi, sensor cross-referencing.

I. INTRODUCTION

A building, a mine roof or a hillside can collapse in seconds because of an earthquake, a landslide, a gas explosion or simply age and poor maintenance. People trapped under the debris can survive only for a limited time, so rescue teams first try to find the exact position of the victim and remove the debris only after that. This work is called Collapsed Structure Search and Rescue (CSSR).

Finding the victim is the slowest and most difficult part of CSSR. Rescuers search by calling out and listening, by using trained dogs, and by removing debris by hand or with machines. This is slow, and moving debris without knowing where the victim is can shift unstable material onto the person. A review of human-detection techniques for debris search points out that time is often decisive and that more advanced systems are needed to locate victims faster and more accurately [1]. Radar is one of the most promising technologies, because radio waves pass through many non-metallic barriers and bring back information about a hidden person [2], and radar on unmanned aerial vehicles (UAVs) has been proposed to survey a large collapsed area quickly [3].

Rural and mining-affected areas face extra difficulty: modern equipment is often not nearby, the ground is unstable, and dust, darkness and heavy rubble hide the victims. A low-cost system that a small rescue team can carry would be very



useful there. This paper studies the **Advance Body Detection System (ABDS)** combined with a thermal camera. The ABDS sends 1.5 GHz radio-frequency (RF) waves into the debris and picks up the reflected signal, while the thermal camera looks for body heat. Using the two sensors together increases confidence of detection and reduces false alarms. The objectives are: (a) to understand the challenges of CSSR in rural and mining-affected areas; (b) to study RF (radar) sensing and thermal imaging for finding trapped victims; (c) to explain the architecture and working of the ABDS and thermal-camera based system; and (d) to list its applications, advantages and limitations. The work was carried out by selecting the topic with the guide, collecting information from recent papers (2020 onwards) and textbooks, comparing the information, and preparing this paper.

II. LITERATURE SURVEY

Table I summarises the papers reviewed. Joret et al. [1] reviewed seven techniques for detecting humans under debris (radar, robotics, drones, gas sensors, optical, acoustic/seismic and infrared) and concluded that more advanced systems are needed. Uzunidis et al. [2] reviewed radar sensors for detecting victims behind large obstacles. Abdelhamid et al. [3] proposed a 24 GHz FMCW radar for collapsed structures, suggested a downward-looking radar on a UAV, and stressed that signal pre-processing is essential. Yang et al. [4] described a handheld IR-UWB through-wall radar that locates a person and measures breathing and heartbeat, and Li et al. [5] used a UWB MIMO imaging radar to locate several persons behind a wall and monitor their vital signs. Adiprabowo et al. [6] used a 77–81 GHz FMCW radar to detect the chest movement of four persons at once, with estimated breathing rates of 10–35 breaths per minute and heart rates of 52–82 beats per minute. On the thermal side, Dong et al. [7] developed a deep-learning detector for survivors in UAV thermal images that runs in real time on UAV-class hardware, and Ulmămei et al. [8] compared human-detection models on embedded platforms.

TABLE I: SUMMARY OF LITERATURE

Ref.	Authors (Year)	Key point for this work
[1]	Joret et al. (2022)	Seven detection techniques compared; faster, more accurate systems needed
[2]	Uzunidis et al. (2023)	Radar can sense hidden victims behind obstacles
[3]	Abdelhamid et al. (2025)	24 GHz FMCW radar on UAV; pre-processing essential
[4]	Yang et al. (2021)	Handheld IR-UWB radar; locates person, senses vital signs
[5]	Li et al. (2021)	UWB MIMO radar; several persons located
[6]	Adiprabowo et al. (2022)	77–81 GHz radar; breathing and heart rate of four persons
[7]	Dong et al. (2020)	Real-time survivor detection in UAV thermal images
[8]	Ulmămei et al. (2025)	Thermal human detection on small embedded boards

Radar-type sensing is described in [2]–[6] and thermal imaging in [7], [8]. Table II compares them: the strengths of one sensor cover the weaknesses of the other, which is the reason for combining them in the ABDS-based system.

TABLE II: RF AND THERMAL SENSING COMPARED

Aspect	RF (radar)	Thermal imaging
Senses	Radio reflection; small movement such as breathing	Heat radiated from the surface
Through debris	Yes, limited depth	No; surface only
Dark, dust, smoke	Not affected	Not affected
False alarms from	Clutter: debris, metal, moisture	Sun-warmed stones, fire, animals

The main observations are: most radar studies use walls or controlled set-ups and not real rubble; unwanted reflections (clutter) can confuse a radar, so signal processing is very important [3]; thermal imaging detects humans well but cannot see through debris [7], [8]; and detection software can run on small embedded boards, which supports portable low-cost systems. In the papers studied, a low-cost, detachable unit combining RF and thermal sensing for rural and mining areas was not found; this is the gap that the ABDS-based system addresses.



III. RESEARCH ELABORATION

A. System architecture

The system can be described with four layers. Data flows upward from the sensors to the rescuer, and control commands such as start and stop flow downward. The **sensing layer** contains the ABDS RF module, which transmits 1.5 GHz waves and receives the reflection, and a thermal camera, both on one detachable unit that can be carried by hand or fitted on a rover or drone. The **data acquisition layer** converts the signals to digital form: an analog-to-digital detector (ADC) samples the RF output and the thermal camera sends pixel values through a digital interface. The **processing layer** filters the RF signal, looks for a human-like pattern, checks the thermal image for body heat and cross-references the two results, using a DSP, microprocessor, Arduino or Raspberry Pi with tools such as GNU Radio and MATLAB [10], [11]. The **application layer** is what the rescuer sees: a screen with the result, an alert such as a buzzer or light, and a marker of the probable victim location.

B. ABDS RF module

Fig. 1 shows the RF module. The **VCO** (voltage-controlled oscillator) generates the signal around 1.5 GHz. The **Tx antenna** radiates it towards the debris and the **Rx antenna** collects the weak waves reflected from the debris and from a buried body. The **LNA** (low noise amplifier) amplifies the weak received signal with very little added noise. The **mixer** multiplies the received signal with a copy of the transmitted signal and gives a low-frequency output that carries the reflection information, and the **ADC** converts this output to digital numbers for the processing unit.

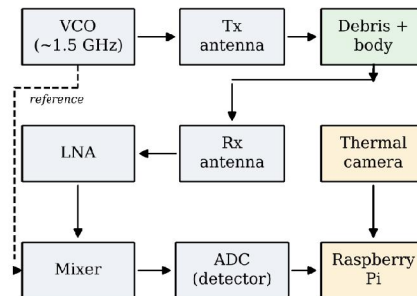


Fig. 1. Block diagram of the ABDS RF module with thermal camera and processing unit

The working idea is simple. Debris and ground give a steady reflection. A living person, however, moves slightly because of breathing, which changes the distance travelled by the wave and therefore the phase of the reflected signal. After mixing, the steady part appears as a constant level that can be filtered out, and the small changing part that repeats at the breathing rate shows that a person may be present. Radar studies have shown that breathing and heartbeat can be measured in this way [4], [6]. The Tx and Rx antennas are kept apart or shielded, because part of the transmitted signal leaks directly into the receiver and can hide the weak reflection.

C. Thermal camera and processing unit

A thermal camera converts infrared radiation into a grid of temperature values. Low-cost thermal array sensors such as the MLX90640, with 32×24 pixels and an I²C interface, are available as small modules [9]. Warm skin or clothing appears as a patch hotter than the surrounding debris. The processing unit collects the data of both sensors. A Raspberry Pi is a small, low-cost computer that can run Python programs, read an ADC and a thermal camera, and drive a display [10]; an Arduino is simpler but has limited speed and memory for image processing. GNU Radio builds real-time signal-processing flows such as filters and spectrum analysis [11], and MATLAB is used for offline analysis and



testing of algorithms. A rechargeable battery with a voltage regulator powers the unit so it can work without mains supply, and a lighter unit is better for drone mounting.

D. Signal processing chain

The raw signals cannot be used directly. The RF branch (1) samples the mixer output with the ADC, (2) removes the steady level of still debris, (3) applies band-pass filtering to keep only the slow breathing range, and (4) applies an FFT and peak detection, where a clear peak in the breathing range suggests a person. The thermal branch (5) reads a thermal frame, (6) subtracts the background to find pixels warmer than their surroundings, and (7) applies a threshold and groups neighbouring warm pixels into a patch with a position. Then (8) the two results and positions are cross-referenced and (9) the result is displayed, alerted and logged. Good pre-processing is essential for reliable detection [3]. The limits used in steps 4 and 7 depend on the hardware and the site and are fixed by trial. A window of some tens of seconds is needed to see a slow breathing signal, so the unit must be kept at one point during each scan.

E. Cross-referencing of RF and thermal data

Each sensor has its own weakness: the RF module can be fooled by metal or uneven debris, and the thermal camera cannot see deep inside rubble. The decision logic is shown in Fig. 2. If no pattern at the breathing rate is found, the unit moves to the next area. If a pattern is found, the thermal image is checked for a warm patch at the same location. If both sensors agree, the location is marked as a confirmed victim and the rescue team is alerted; if only one sensor shows a result, the place is marked as a possible false alarm and is re-scanned or checked manually. Because the position of the unit at each scan point is known, the confirmed point can be marked on a simple map so that digging starts at the right place.

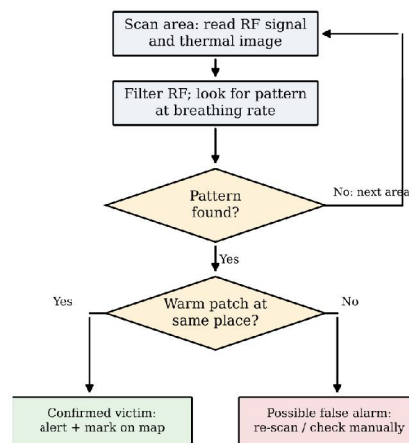


Fig. 2. Flowchart of RF and thermal cross-referencing

IV. RESULTS AND DISCUSSION

This study is based on published literature and general technical principles; no experiments were carried out. The values below are typical or assumed values for explanation and must be confirmed by measurement on real hardware.

A. Choice of frequency

Radio waves pass through dry brick, concrete, wood and soil, and part of the wave is reflected wherever the material changes. The human body contains much water (relative permittivity about 80) while dry building material has only a few units, so the body reflects differently and is visible to a radar even when hidden. Lower frequencies penetrate deeper but give poor resolution and need larger antennas; higher frequencies give finer detail but are absorbed and



scattered more by debris. The ABDS uses 1.5 GHz, a practical compromise between penetration, resolution and antenna size.

B. Basic calculations

Wavelength. With $c = 3 \times 10^8$ m/s and $f = 1.5 \times 10^9$ Hz:

$$\lambda = c / f = 0.2 \text{ m} = 20 \text{ cm} \quad (1)$$

In dry brick or concrete with relative permittivity of about 4, the wavelength becomes $\lambda/\sqrt{4} = 10$ cm. A printed patch antenna for 1.5 GHz on FR-4 is expected to be about 5 cm $\times$ 6 cm.

Range resolution. If the VCO is swept over a bandwidth B (FMCW mode):

$$\Delta R = c / (2B) \quad (2)$$

For an example sweep of 200 MHz, $\Delta R = 0.75$ m in air. This is coarse, so the exact position is found by scanning from several points and by using the thermal image.

Breathing signal. If the chest moves by a distance d, the phase change is:

$$\Delta\phi = 4\pi d / \lambda \quad (3)$$

For $d = 5$ mm and $\lambda = 0.2$ m, $\Delta\phi = 0.314$ rad (about 18°); in material with permittivity 4 ($\lambda = 0.1$ m) it is about 36° , but the signal is also weakened by the debris. Breathing rates of 10–35 per minute [6] correspond to 0.17–0.58 Hz.

Sampling. Since the signal of interest is below about 1 Hz, 50 samples per second is more than enough. A 30 s window analysed by FFT gives a frequency resolution of $1/T = 0.033$ Hz, about 2 breaths per minute.

Thermal coverage. A 32×24 array with a $55^\circ \times 35^\circ$ field of view [9] gives about 1.7° per pixel. At 3 m one pixel covers about 9 cm and the image covers about 3.1 m in width, so a 40 cm wide body covers about 4 pixels across, enough to see a warm patch.

TABLE III: SUMMARY OF BASIC CALCULATIONS

Quantity	Formula	Example value
Wavelength, 1.5 GHz	$\lambda = c/f$	20 cm in air
Range resolution	$\Delta R = c/(2B)$	0.75 m (200 MHz)
Phase, 5 mm movement	$\Delta\phi = 4\pi d/\lambda$	0.314 rad ($\sim 18^\circ$)
Frequency resolution	$1/T$	0.033 Hz (30 s)
Thermal pixel at 3 m	$3 \times \tan(1.7^\circ)$	About 9 cm

C. Practical issues

A large part of the reflected signal comes from the surface of the debris and objects inside it; this clutter, and multipath reflections, can be reduced by removing the steady level and comparing successive scans, but never removed completely [3]. Metal such as reinforcing bars reflects radio waves almost completely, and wet debris absorbs more energy, so penetration depth becomes smaller; a negative RF result therefore does not prove that nobody is present, and the scan should be repeated from other positions. Thermal readings depend on emissivity, distance and surroundings, a thin layer of dust or cloth lowers the apparent temperature, and in hot daytime conditions sun-heated debris can be as warm as a body, so the thermal result is checked together with the RF result and not alone.

D. Applications

In **mines**, roof falls trap workers in dark, dusty, unstable places, and a small portable unit carried by a rover lets rescuers stay at a safe distance. In **rural disaster and landslide zones**, heavy equipment and dog squads may take hours to arrive, and a low-cost battery-powered unit lets local volunteers start the search early. In **collapsed buildings and construction sites**, the unit can scan rubble from the surface to find where a person may be trapped before digging. Because the unit is detachable, it can be fitted on a ground rover or a drone; weight, power and vibration must be checked before such mounting [3], [7], [8]. In a typical case, a small house collapse after heavy rain, an RF breathing-rate peak without a warm patch is marked as a possible detection and re-scanned from another side; when the



peak appears again together with a warm patch at a gap between slabs, the detection is confirmed and the team digs carefully there. The system only helps to decide where to start; the rescue is done by the trained team.

E. Advantages, limitations and comparison

The advantages are higher detection confidence from two independent sensors, non-invasive detection without moving debris, operation in darkness and dust, rapid on-the-spot identification, low cost from commercially available modules, and a detachable, flexible unit. Table IV lists the limitations with possible remedies.

TABLE IV: LIMITATIONS AND POSSIBLE REMEDIES

Limitation	Possible remedy
Reflections from debris, metal, wet material give false detections	Filtering; confirm with thermal camera
Limited penetration through thick, wet or metal-reinforced debris	Scan from several positions; adjust gain
Thermal sees only surface heat; warm objects confuse it	Use thermal only to confirm RF detection
Interference, dust, moisture, uneven ground	Shielded box; site calibration; adaptive filtering
Transmission must follow regulator rules and safe power	Low power; check WPC rules before use
Battery life and weight limit drone use	Suitable battery; keep unit light
Rescuers need training	Simple display; demonstrations

Compared with other approaches, manual search is slow and risky for rescuers, search dogs need trained dogs and handlers, a thermal camera alone cannot see through debris, and an RF sensor alone gives false detections from clutter. The ABDS (RF + thermal) can find hidden victims to a limited depth, works in darkness and reduces false alarms, but needs field testing.

F. Safety and regulatory points

The transmitted power must be kept low and the unit should not be pointed at people from a short distance during tests. Use of a transmitter in a given band must follow the rules of the regulator in India (Wireless Planning and Coordination wing). An alert must always be checked by the team, and a negative result must never be taken as proof that nobody is present. During development no person should be buried or placed under heavy material; a volunteer behind a light barrier and a warm test object are safe ways to test.

V. CONCLUSION AND FUTURE SCOPE

This paper studied RF sensing and thermal imaging for finding victims in CSSR, with special attention to rural and mining-affected areas. The four-layer architecture of the ABDS was explained, together with the roles of the Tx/Rx antennas, VCO, LNA, mixer and ADC in the 1.5 GHz RF module, the thermal camera, and the processing unit. The literature shows that radar can sense hidden persons and their breathing and that thermal imaging can detect humans in darkness, but each has limits alone. By cross-referencing the two, the system gives a more confident detection and fewer false alarms. Its main limitations are unwanted reflections, limited penetration depth, regulations on radio transmission and the need for field trials. The ABDS-based system is therefore a useful and practical idea for faster and safer search and rescue in rural and mining-affected areas.

Future work includes mounting the detachable unit on drones and rovers, using artificial intelligence and machine learning to identify victims automatically and reduce false positives, wireless transmission of victim location to rescue teams through a mobile application, and improved antennas, wider RF bandwidth and better signal processing for greater penetration depth and accuracy. Field trials on real debris are needed before the performance of the system can be stated.



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