

A Low-Cost Multimodal Detector for Emergency Signals and Closed-Loop Search Guidance: A Prototype Study Using Controlled RF, Audio, and Vibration Tests

Yuchun Hui 

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Abstract: Rapid survivor search after structural collapse, flooding, avalanche burial, or other disasters can be limited because trapped people may produce only weak, irregular, and non-coded cues, such as tapping, whistles, short voice calls, or incidental electromagnetic pulses. This study evaluated whether a low-cost, student-built prototype could support a bounded search workflow by combining a 457-kHz-centered radio frequency (RF) receive channel with close-range audio and vibration confirmation.

The prototype used a low-frequency RF receiver, microphone channel, piezo-vibration channel, and microcontroller firmware based on three interpretable criteria: energy, band consistency, and rhythm. Controlled educational tests included a low-power 457-kHz reference source for line-of-sight RF trials, structured tapping and whistle/voice tests for near-field confirmation, and supervised impulsive-source trials for classifier stress testing. Construction and operating details for any potentially misused signal source are omitted; a software-defined radio receiver was used only for passive spectral observation and did not participate in detection decisions.

In the baseline RF test, the system detected 58 of 60 trials at 100 m line of sight, or 96.7% detection. During 1 hour of silent monitoring, no false alarms were observed, corresponding to an approximate upper 95% false-alarm bound of 3 events per hour. In close-range confirmation tests, knock detection ranged from 60.0% to 95.0% depending on the contacted material, and whistle/voice confirmation was strongest at 1–5 m but declined at longer corridor distances. In classifier-ablation trials, the full energy/band/rhythm method achieved 90.0% detection at the shorter building-path scale and 70.0% at the longer path scale, both with zero false alarms in those runs. In a small pilot search drill, brief training reduced mean time to first detection from 6.83 ± 1.82 min to 4.20 ± 0.46 min and mean path length from 156 ± 31 m to 104.7 ± 7.5 m.

These results support the feasibility of a low-cost multimodal prototype for education, drills, and supervised research. The system is not a certified rescue device or a precise localization instrument; its contribution is a receiver-and-classifier framework for coarse cue capture, near-field confirmation, and operator search guidance.

Author keywords: Emergency-signal detection; Multimodal sensing; 457-kHz RF; Audio–vibration confirmation; Search guidance

Introduction

In many disasters, the first communication problem is not only range but signal form. After collapse or isolation, survivors may not possess a certified beacon, a functioning mobile connection, or enough physical strength to sustain loud vocal calls. Emergency preparedness guidance often recommends conserving energy and using repeated signals such as knocking or whistling when possible.¹ These cues can be generated without special equipment, but they are weak, irregular, and easy to confuse with environmental noise.

Certified emergency systems solve a different problem. The Cospas-Sarsat system now relies on 406-MHz

digital distress beacons for satellite alerting, while 121.5 MHz remains mainly a homing or guarded emergency frequency.^{2,3,4} Avalanche-rescue transceivers are standardized around 457 kHz and use low-frequency magnetic-field coupling for short-range burial search.⁵ Other rescue technologies, including RECCO and microwave radar, add useful capabilities but often require certified devices, trained operators, or costly infrastructure.^{6–9}

This study grew from an earlier student project on simple life-protection and emergency-rescue systems under extreme conditions. That work showed an important engineering lesson: a signal that can be produced is not necessarily a signal that can be stably detected or used for search. The present manuscript therefore shifts the claim to the safer receiver side: controlled signal detection, interpretable decision fusion, and bounded search guidance.

*Corresponding Author: Yuchun Hui. Email: stoneyhui@163.com
Beijing Normal University Asia-Pacific Experimental School, Beijing 102209, China

The research question is whether a low-cost prototype can combine a 457-kHz-centered radio frequency (RF) receive path with audio–vibration confirmation and Energy/Band/Rhythm voting to detect non-coded emergency cues more reliably than energy-only detection. The study contributes a supervised educational prototype, a transparent microcontroller logic, controlled tests in real bench and field environments, and a small pilot drill on operator training. It does not propose a new distress-transmission method and does not provide operational instructions for constructing transmitters or hazardous sources (Figure 1).

Figure 1. Prototype receiver and closed-loop search-guidance concept

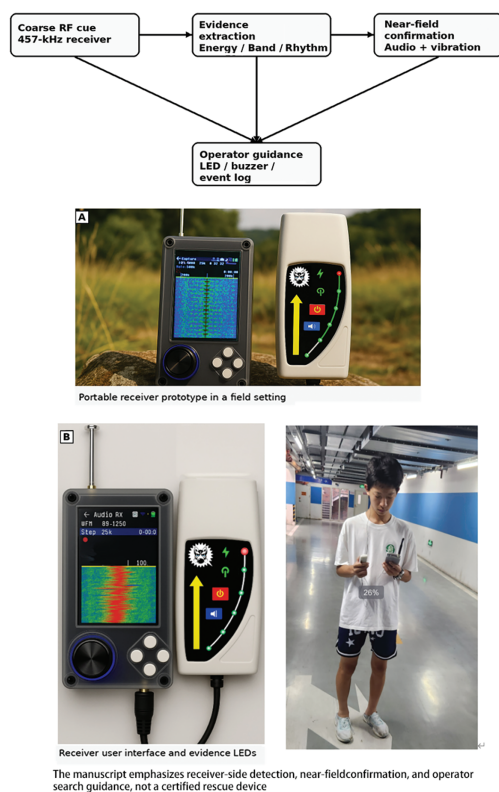


Figure 1. Prototype receiver and search-guidance concept. Panel A shows the portable receiver prototype in a field setting; Panel B shows the receiver user interface and evidence LEDs; the workflow summarizes coarse RF cue capture, Energy/Band/Rhythm extraction, near-field audio–vibration confirmation, and operator guidance. The prototype was evaluated as a detection and search-guidance system, not as a certified rescue device or a precise localization instrument. LED, light-emitting diode; RF, radio frequency

Description, Methodology, or Proposed Research Approach

Study design

The prototype was designed as a portable educational detector for supervised search-and-rescue research. Its workflow

is simple: capture a candidate RF cue, confirm proximity with short-range audio or vibration channels, and display the evidence state so the operator can adjust the search path. Each alert is traceable to a small set of criteria that can be inspected, logged, and explained to new users.

The work was evaluated as an engineering proof of concept. The dependent variables were detection rate, observed false alerts, time to first detection in a pilot drill, and search path length. Claims are restricted to the tested educational scenarios. The system is not a certified avalanche transceiver, 406-MHz beacon, microwave-vital-sign radar, or professional rescue instrument.

Prototype architecture and decision logic

The receiver contained three sensing paths. The first path was a low-frequency RF channel centered near 457 kHz, using a ferrite-rod antenna, analog preselection, envelope detection, low-pass smoothing, and low-rate digitization. Because low-frequency RF response depends strongly on geometry, coupling, and path conditions, the RF channel was evaluated empirically as a cue-detection path rather than as a calibrated ranging link.¹⁰

The second path was an electret-microphone channel for whistles and nearby voice cues. The third path was a piezo-electric vibration channel for contact or near-contact knock detection. A microcontroller performed event extraction, vote fusion, timing checks, user-interface updates, and event logging (Figure 2).

The firmware used three criteria. Energy assessed whether a short-window signal rose above an adaptive baseline. Band assessed whether the signal matched the expected band-limited structure. Rhythm assessed whether repeated onsets occurred within a loose timing window consistent with intentional signaling. The RF channel used Energy AND Band, the audio channel used majority voting across Energy, Band, and Rhythm, and the vibration channel used Energy AND Rhythm (Table 1). The design draws on short-time energy, onset detection, and low-complexity signal-processing concepts, but was simplified for microcontroller use.^{11–16}

Controlled test-signal sources and compliance

All experiments were framed around controlled test sources. A low-power laboratory reference source near 457 kHz was used for baseline and movement trials. Human-generated cues, including whistles, short voice calls, and tapping, were used for close-range confirmation tests. A separate supervised impulsive broadband source coupled to pre-existing metal structures was used only to stress test the classifier. Source construction, switching, coupling, and operating details are intentionally omitted because they are not needed to interpret receiver performance and could be unsafe if replicated without supervision.

A software-defined radio receiver was used only for passive observation of nearby spectrum activity, including passive monitoring near 121.5 MHz. It did not transmit, did not enter the voting algorithm, and did not contribute to reported detection statistics. Photographs of receiver-side bench and field tests are included to document the tested

Figure 2. Receiver architecture and interpretable E/B/R evidence mapping

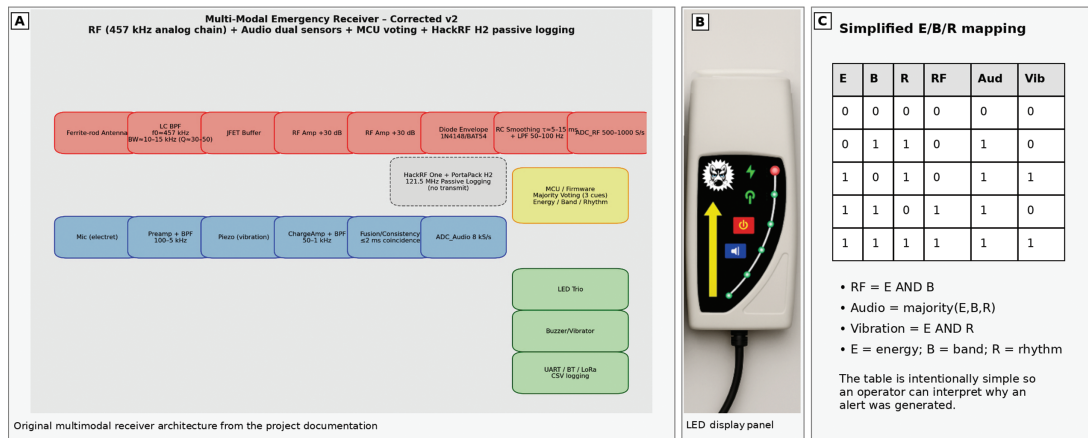


Figure 2. Receiver architecture and interpretable Energy/Band/Rhythm evidence mapping. The RF channel supplies coarse cue capture; microphone and piezo-vibration channels support near-field confirmation; the LED truth table maps low-level evidence to channel-level outputs. E/B/R, Energy/Band/Rhythm; LED, light emitting diode; RF, radio frequency

Table 1. Simplified decision mapping used in the journal version. Additional receiver-side firmware details can be provided by the author upon reasonable request

Criterion state	RF output	Audio output	Vibration output	Interpretation
E = 0, B = 0, R = 0	0	0	0	No evidence
E = 0, B = 1, R = 1	0	1	0	Possible structured sound without strong energy
E = 1, B = 0, R = 1	0	1	1	Likely repeated knock/vibration cue
E = 1, B = 1, R = 0	1	1	0	Band-consistent RF or audio cue
E = 1, B = 1, R = 1	1	1	1	Strong multimodal evidence

Note: RF, radio frequency.

environments, while source-construction details that could enable unsafe replication are not shown (Figure 3).

Experimental procedures

Five groups of experiments were retained from the original study. First, a silent-monitor trial was run for 1 h after threshold stabilization. Second, baseline RF trials were performed for a 100-m line-of-sight case and for outdoor, water-adjacent, and urban-overpass conditions. These field trials included stationary testing, transmitter-moving and receiver-moving testing, water-to-land and land-to-water testing, and an urban overpass trial with metal railings, traffic, and a more complex electromagnetic background. Each main RF condition used 60 attempts.

Third, vibration tests were performed by contacting the piezo channel to different materials and generating approximate 1-Hz knock patterns. Fourth, close-range audio tests were performed with whistles and short voice calls in a classroom and corridor setting. The classroom audio test used background music near the detector to create a 75–82-dBA noise environment. Fifth, an ablation study was performed at two approximate building-path scales using the controlled impulsive source and multiple logic configurations.

A small pilot search drill was retained because it tested operator search guidance. The drill compared minimally trained users with briefly trained users while holding device and source conditions constant across three rounds. Time to first detection and path length were recorded. Path length was estimated by step counting after a 20-m step-length calibration and selected 20–30-m tape checks, giving approximately 3–5% path-length error.

Because this was a single-student high-school project, the operator drill used available family volunteers and a single prototype under adult supervision. A larger human-operator dataset could not be collected within the available school schedule, field-site access, participant availability, and safety-supervision constraints. Therefore, the drill is reported as descriptive pilot evidence rather than a population-level human-factors result.

Statistical treatment

Detection rates are reported as successes divided by trials, with exact Clopper–Pearson 95% confidence intervals for key binomial proportions.¹⁷ For the silent-monitor test, where zero false alarms were observed over time T, the upper 95% event-rate bound was approximated with the rule of three, 3/T.¹⁸ No inferential statistical test was applied to the

Figure 3. Controlled bench, outdoor, water-adjacent, indoor, and urban test environments

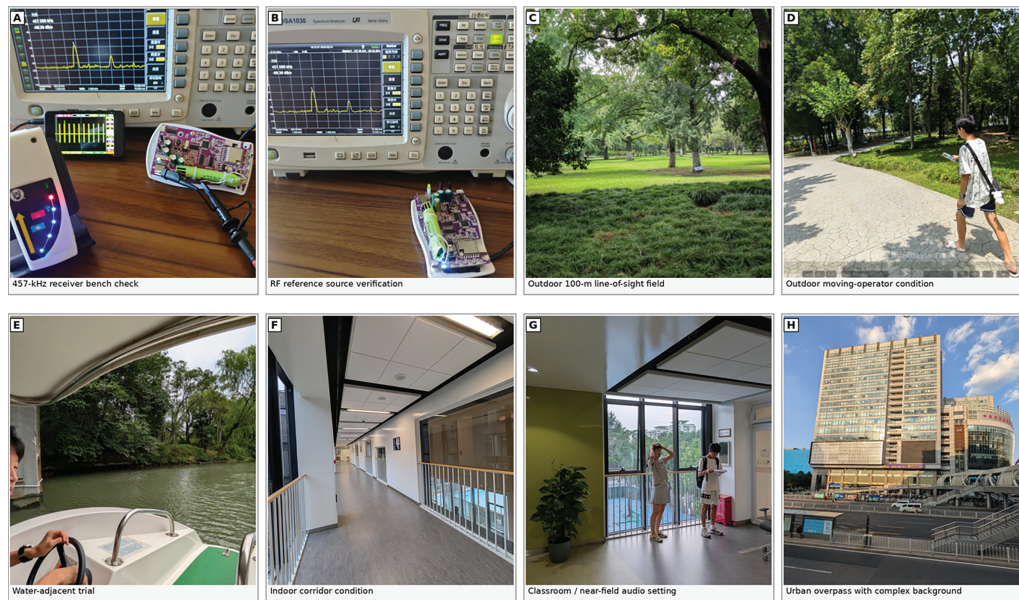


Figure 3. Controlled bench, outdoor, water-adjacent, indoor, and urban test environments. The photographs document receiver-side bench verification, outdoor 100-m line-of-sight trials, moving and water-adjacent field trials, corridor/classroom confirmation tests, and an urban-overpass environment. Potentially hazardous source-construction details are intentionally not shown

pilot drill because the number of users and rounds was too small for population-level claims.

Experimental Design and Results

Baseline RF performance

The strongest baseline result was obtained in the 100 m line-of-sight reference condition, where the device achieved 58/60 detections, corresponding to 96.7% detection with a 95% confidence interval of approximately 88.5–99.6%. Performance remained high but lower in more realistic cases, including movement, water-adjacent geometry, and the urban-overpass setting. The pattern indicates that the RF channel preserved useful cue sensitivity across non-ideal conditions while still degrading when path complexity increased (Table 2; Figure 4).

False-alert behavior

In a 1-h silent-monitor run after threshold adaptation, the device produced zero false alarms. This should not be interpreted as proof of a true zero false-alarm rate. Using the rule of three, the approximate upper 95% false-alarm bound is 3 events per hour. The 1-hour test is short, but it is useful as a practical screen because alert burden is an important usability constraint for a volunteer-facing detector.

Structural knock and audio-confirmation tests

Close-range confirmation behaved differently across modalities. Rigid metallic coupling improved vibration transfer, while softer or less-coupled structures degraded it. During

testing, the piezo sensor could be fixed with tape or pressed by hand against a target surface. Loose contact could create friction-like false events, while excessive pressure could raise the baseline and reduce sensitivity to smaller vibrations. These practical details mattered as much as the nominal sensor specification.

For audio, whistle and voice cues were strongest at close range but declined in corridor tests. The 1-m classroom test was run in a noisy environment of approximately 75–82 dBA to check whether the microphone channel could still respond under realistic background noise. These results support an operational division of labor: audio and vibration are useful chiefly for near-field confirmation, not for tens-of-meters primary search (Table 3; Figure 5).

Classifier-ablation trials

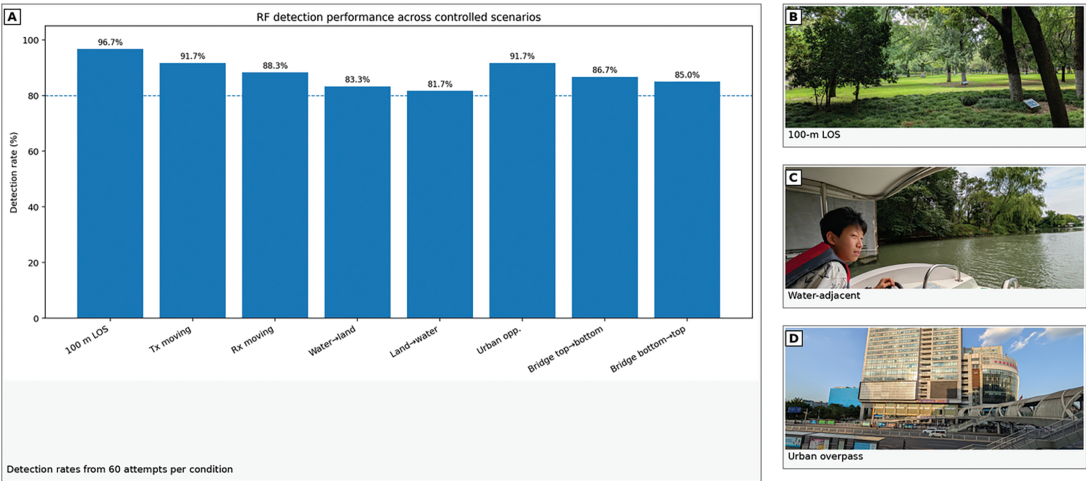
The classifier-ablation results are central because they test the value of decision logic rather than hardware alone. At the shorter building-path scale, the full Energy + Band + Rhythm configuration achieved 45/50 detections with zero false alerts. Removing Rhythm or Band preserved similar detection but increased false alerts. Energy-only detection with a low threshold increased nominal sensitivity but produced more false alerts; energy-only detection with a high threshold suppressed false alerts but lost sensitivity. At the longer path scale, the same tradeoff appeared more strongly. The engineering conclusion is straightforward: the extra criteria reduced the sensitivity-versus-false-alert trade-off (Table 4; Figure 6).

Table 2. RF detection performance using the controlled 457-kHz reference cue. Each condition used 60 attempts

Condition	Detected/attempts	Detection rate	Notes
100 m line of sight, both stationary	58/60	96.7%	No false alert observed
Outdoor, transmitter moving	55/60	91.7%	Stable detection
Outdoor, receiver moving	53/60	88.3%	Moderate degradation
Water-surface transmitter, land receiver	50/60	83.3%	Moderate degradation
Land transmitter, water-surface receiver	49/60	81.7%	Some interference noted
Urban overpass, opposite sides	55/60	91.7%	Complex electromagnetic background
Bridge top to bridge bottom	52/60	86.7%	Complex geometry
Bridge bottom to bridge top	51/60	85.0%	Complex geometry

Note: RF, radio frequency.

Figure 4. RF detection performance across baseline and non-ideal field scenarios



Field insets document that RF tests included static line-of-sight, movement, water-adjacent, and urban-overpass conditions.

Figure 4. RF detection performance across baseline and non-ideal field scenarios. Detection rates are based on 60 attempts per condition. Field insets document the line-of-sight, water-adjacent, and urban-overpass settings. RF, radio frequency

Pilot operator drill

The pilot search drill tested whether brief training could help users follow the detector more efficiently. Across three rounds, the novice group required 6.83 ± 1.82 min to first detection, whereas the briefly trained group required 4.20 ± 0.46 min, a reduction of about 38.6%. Mean path length decreased from 156 ± 31 m to 104.7 ± 7.5 m, a reduction of about 32.9%. The round-by-round values indicate that novices improved with repetition, but the trained group remained faster and more direct (Table 5; Figure 7).

These results should be treated as descriptive usability evidence only. The drill used a small convenience sample of available family volunteers because recruiting a larger group and reserving controlled field sites were not feasible within the project schedule and safety constraints. The outcome suggests that training may matter, but it does not establish a population-level human-factors conclusion.

Discussion and Guidelines for Applications

The retained results support a practical division of labor across sensing modes. The RF path served as the coarse cue channel at tens of meters. The audio and vibration paths were more limited in range, but this defines their role: they provide near-field confirmation when the operator is close enough for sound or structural coupling to matter.

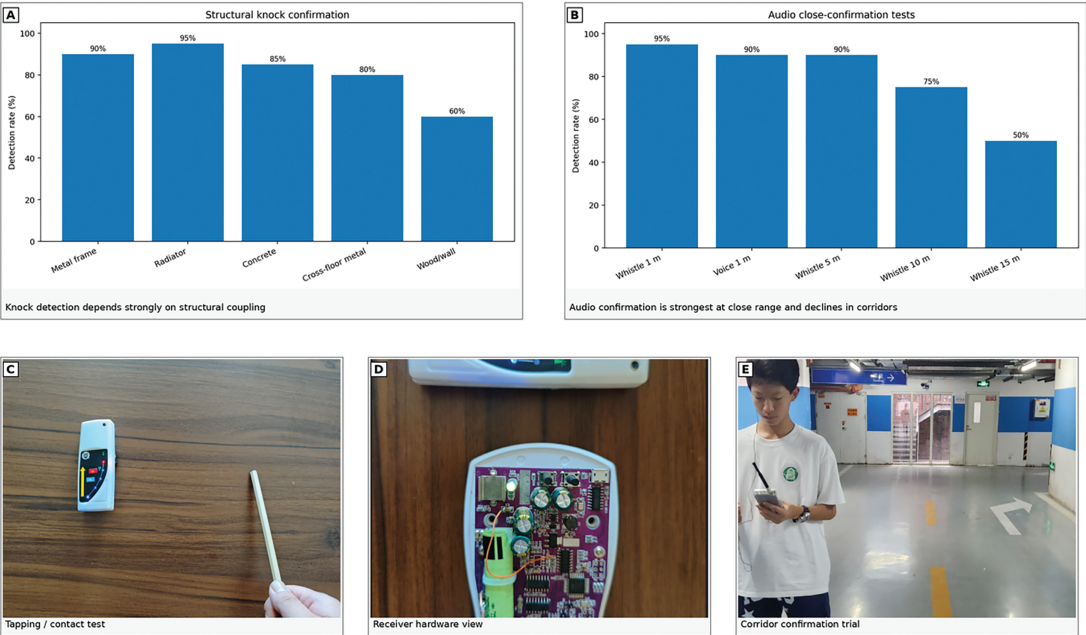
The Energy/Band/Rhythm logic also made the detector more interpretable. The ablation results show why this matters: when individual criteria were removed, false-alert counts increased even when raw detection rate stayed similar. For student or volunteer contexts, the detector should show what evidence is accumulating rather than only emit a warning.

The prototype should be described as an educational, drill-oriented, supervised research instrument. It should not be described as a certified rescue beacon, a substitute for 406-MHz emergency beacons, a substitute for professional

Table 3. Close-range confirmation performance for structural knock and audio cues

Cue and condition	Detected/attempts	Rate	Interpretation
Metal door-frame knock, approximately 1 Hz	18/20	90.0%	Structural vibration confirmation
Radiator knock, approximately 1 Hz	19/20	95.0%	Best rigid-metal coupling
Concrete wall knock, approximately 1 Hz	17/20	85.0%	Moderate coupling
Cross-floor metal component knock	16/20	80.0%	Longer structural path
Wood/wall knock	12/20	60.0%	Weak coupling
Whistle at 1 m, 75–82-dBA background	19/20	95.0%	Channel self-check/close confirmation
Short voice call at 1 m, 75–82-dBA background	18/20	90.0%	Voice event detection, not semantic recognition
Corridor whistle at 5 m	18/20	90.0%	Near confirmation
Corridor whistle at 10 m	15/20	75.0%	Clear distance degradation
Corridor whistle at 15 m	10/20	50.0%	Boundary condition for this prototype

Figure 5. Close-range vibration and audio confirmation tests



These panels help show how close-confirmation results were collected in real indoor settings, not only as abstract tables.

Figure 5. Close-range vibration and audio confirmation tests. Structural knock detection depended strongly on material coupling, while audio confirmation was strongest at close range and declined in corridor tests

avalanche transceivers, or a substitute for microwave-vital-sign radar. Training or demonstration settings should rely on nonhazardous cues such as whistle and tapping exercises, passive spectrum observation, or institutionally controlled laboratory reference sources.

Detection versus localization accuracy

This study primarily evaluates signal detection and operator search guidance rather than precise localization accuracy. The prototype can identify candidate cues and help an operator approach a likely source, but the experiments did not measure absolute localization error, angular error, or three-dimensional position accuracy in rubble-like environments. The pilot drill outcomes, including time to first detection and

path length, therefore indicate guidance usefulness rather than formal localization performance.

A future localization study should use hidden source coordinates, blinded placement, repeated starting points, directional RF measurements, multi-node receiver configurations, and distance-error metrics. Such tests would allow the system to be evaluated as a localization aid rather than only as a detector and guidance prototype.

Limitations

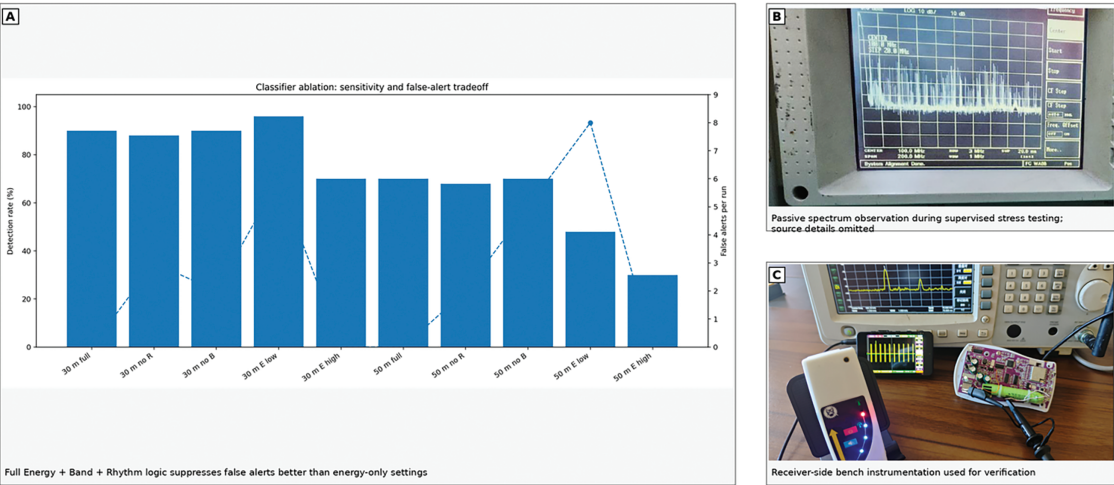
Several limitations constrain the claims. First, all experiments were small in scale and scenario-specific. Second, the RF path was evaluated mainly as a detectability channel, not as a calibrated ranging system. Third, the

Table 4. Classifier ablation using a controlled impulsive test source. Each condition used 50 attempts

Path scale	Logic setting	Detected attempts	Rate	False alerts
Approx. 30 m	Full E + B + R	45/50	90.0%	0
Approx. 30 m	Remove rhythm	44/50	88.0%	3
Approx. 30 m	Remove band	45/50	90.0%	2
Approx. 30 m	Energy only, low threshold	48/50	96.0%	6
Approx. 30 m	Energy only, high threshold	35/50	70.0%	0
Approx. 50 m	Full E + B + R	35/50	70.0%	0
Approx. 50 m	Remove rhythm	34/50	68.0%	2
Approx. 50 m	Remove band	35/50	70.0%	5
Approx. 50 m	Energy only, low threshold	24/50	48.0%	8
Approx. 50 m	Energy only, high threshold	15/50	30.0%	0

Note: E + B + R, Energy + Band + Rhythm.

Figure 6. Classifier ablation and passive spectral observation during stress testing



Only receiver-side and observation panels are used in the revision. Construction/operation details for hazardous or misuse-prone sources should

Figure 6. Classifier ablation and passive spectral observation during stress testing. The full Energy + Band + Rhythm method preserved usable sensitivity while suppressing false alerts better than energy-only settings. Only receiver-side and passive observation views are shown; source construction and operating details are omitted

pilot drill involved too few rounds and participants for population-level conclusions about training effects. Fourth, some original competition material blurred the boundary between detector research and source construction; this manuscript keeps the scientific emphasis on receiver design, decision logic, and safe evaluation.

Recommendations for Future Work

The next stage should improve replication quality before adding features. The most valuable additions would be a preregistered test matrix, longer silent-monitor runs, independent repeat testing in multiple buildings, and cleaner separation of long-range RF detection from near-range

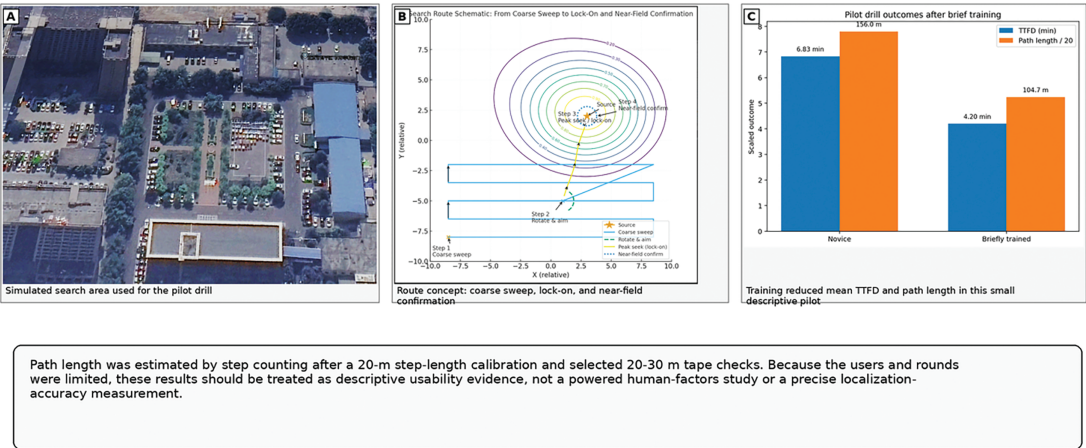
confirmation outcomes. Future experiments should also increase the number of trials, users, buildings, and source placements, especially for operator training and localization-related outcomes.

On the hardware side, future work could evaluate more directional RF front ends, better shielding, and multi-node consensus across several receivers. On the data side, future work should release raw comma-separated values (CSV) files in a structured supplement, document firmware versions and calibration conditions, and include receiver-only schematics and a bill of materials. On the human-factors side, future work should test training effects with more participants, randomized starting locations, blinded source placement, and prespecified success criteria.

Table 5. Pilot drill summary. TTFD, time to first detection

Group	Mean TTFD	Mean path length	Interpretation
Novice users	6.83 ± 1.82 min	156 ± 31 m	Improved across rounds but less direct
Briefly trained users	4.20 ± 0.46 min	104.7 ± 7.5 m	Faster and more stable
Relative change	−38.6%	−32.9%	Descriptive pilot comparison only

Figure 7. Pilot search-guidance drill: site, route concept, and descriptive outcomes



$$D = N \times \bar{L}$$

Step-count path estimate

Figure 7. Pilot search-guidance drill: site, route concept, and descriptive outcomes. The drill evaluated operator search guidance using time to first detection and path length. It does not measure precise localization accuracy. TTFD, time to first detection

Conclusions

This study demonstrates that a portable, low-cost multi-modal detector can combine low-frequency RF cue capture with near-range audio and vibration confirmation in one search-guidance workflow. The strongest findings are the 96.7% detection result in the 100-m line-of-sight baseline, the 1-hour silent-monitor result, the ablation evidence showing the benefit of multi-criterion logic, and the pilot drill showing shorter search times and more direct routes after brief training.

The manuscript’s key boundary is also its key safety correction: it presents the work as a receiver-and-classifier study, not as an operational signaling manual. The pilot drill suggests search-guidance usefulness, but the prototype has not yet been validated for precise localization in rubble-like environments. Within these boundaries, the project can be strengthened further through better replication, cleaner supplementary data, and receiver-only open documentation.

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References

- [1] American Red Cross. *Earthquake Safety*. Washington, DC: American Red Cross; n.d. <https://www.redcross.org/get-help/how-to-prepare-for-emergencies/types-of-emergencies/earthquake.html>.
- [2] Cospas-Sarsat. *Cospas-Sarsat System Data No. 50*. Montreal: International Cospas-Sarsat Programme; 2024. <https://www.cospas-sarsat.int/en/documents-pro/system-data>.
- [3] National Oceanic and Atmospheric Administration. *Emergency Beacon Testing*. Silver Spring, MD: NOAA SARTSAT; n.d. https://www.sarsat.noaa.gov/emergency_beacon-testing/.

- [4] Federal Aviation Administration. *Aeronautical Information Manual, Chapter 6, Section 2: Emergency Services Available to Pilots*. Washington, DC: FAA; n.d. https://www.faa.gov/air-traffic/publications/atpubs/aim_html/chap6_section_2.html.
- [5] European Telecommunications Standards Institute. *EN 300 718-1 V2.1.0: Avalanche Beacons Operating at 457 kHz; Transmitter-Receiver Systems; Part 1: Harmonised Standard for Access to Radio Spectrum*. Sophia Antipolis: ETSI; 2017. https://www.etsi.org/deliver/etsi_en/300700_300799/30071801/02.01.00_20/en_30071801v020100a.pdf.
- [6] Recco AB. *Technology*. Lidingo: RECCO AB; n.d. <https://recco.com/technology/>.
- [7] Alvarez-Merino CS, Cejudo-Lopez JM, Garcia-Carrasco I, et al. Victim detection and localization in emergencies. *Sensors*. 2022;22(21):8433. doi:10.3390/s22218433.
- [8] Nguyen Thi Phuoc Van N, Tang L, Demir V, Hasan SF, Nguyen DM, Mukhopadhyay S. Review-microwave radar sensing systems for search and rescue purposes. *Sensors*. 2019;19(13):2879. doi:10.3390/s19132879.
- [9] Donelli M. A rescue radar system for the detection of victims trapped under rubble based on the independent component analysis algorithm. *Prog Electromagn Res M*. 2011;19:173–181. doi:10.2528/PIERM11051006.
- [10] Rappaport TS. *Wireless Communications: Principles and Practice*. 2nd ed. Upper Saddle River, NJ: Prentice Hall; 2002.
- [11] Bello JP, Daudet L, Abdallah S, Duxbury C, Davies M, Sandler MB. A tutorial on onset detection in music signals. *IEEE Trans Speech Audio Process*. 2005;13(5):1035–1047. doi:10.1109/TSA.2005.851998.
- [12] Dixon S. Onset detection revisited. *Proceedings of the 9th International Conference on Digital Audio Effects; 2006 September 18–20; Montreal, Canada*. pp. 133–137. https://www.dafx.de/paper-archive/2006/papers/p_133.pdf.
- [13] Mesaros A, Heittola T, Virtanen T, Plumbley MD. Sound event detection: a tutorial. *IEEE Signal Process Mag*. 2021;38(5):67–83. doi:10.1109/MSP.2021.3090678.
- [14] Quatieri TF. *Discrete-Time Speech Signal Processing: Principles and Practice*. Upper Saddle River, NJ: Prentice Hall; 2002.
- [15] Texas Instruments. Designing an anti-aliasing filter for ADCs in the frequency domain. *Analog Appl J*. 2015;2Q:7–11. <https://www.ti.com/lit/an/slyt630/slyt630.pdf>.
- [16] Horowitz P, Hill W. *The Art of Electronics*. 3rd ed. Cambridge: Cambridge University Press; 2015.
- [17] Clopper CJ, Pearson ES. The use of confidence or fiducial limits illustrated in the case of the binomial. *Biometrika*. 1934;26(4):404–413. doi:10.1093/biomet/26.4.404.
- [18] Hanley JA, Lippman-Hand A. If nothing goes wrong, is everything all right? Interpreting zero numerators. *J Am Med Assoc*. 1983;249(13):1743–1745. doi:10.1001/jama.1983.03330370053031.

About the Author



Yuchun Hui is a tenth-grade student at Beijing Normal University Asia-Pacific Experimental School in Beijing, China. His research interests include Arduino/MCU programming, low-power embedded hardware, power management, battery-powered devices, Python software engineering, and lightweight data pipelines. He has developed student research projects across emergency-signal detection, geospatial computation, and AI-assisted science learning, with a particular interest in building small,

explainable prototypes that connect physics, computation, and real-world problem solving. In the present work, he designed and tested a low-cost multimodal receiver that combines 457-kHz RF sensing with audio and vibration confirmation for supervised search-guidance experiments.