Rapid Search-and-Rescue System for Buried Victims in Typical Disaster Scenarios

Hao Shi[1], Yudong Fang[1]*, Wei Guo[1], Qunying Zhang[2]

[1]Ministry of Emergency Management Big Data Center, Beijing, China
[2]Aerospace Information Research Institute, Chinese Academy of Sciences, Beijing, China

*20714787@qq.com

Abstract. Facing typical disasters such as earthquakes, landslides, and debris flows—characterized by sudden onset, high destructiveness, and wide-area impact—rapid post-disaster rescue of trapped individuals is the core objective of emergency relief. To improve the efficiency of locating and rescuing those trapped, this work analyzes the operational characteristics of diverse search technologies and equipment. It integrates the disaster-caused features of typical scenarios, the entrapment environment, and the distribution of entrapment to establish an air–space–ground–human integrated three-dimensional search pattern. This framework enables the coordination of multiple sensing platforms, fusion of heterogeneous data, and joint operations by responders, thereby providing a new paradigm for rapid and precise detection of large-scale, deeply buried targets in wide-area search and rescue(SA).

Keywords*:* typical disaster scenarios, search - and - rescue of buried and trapped targets, search - and - rescue operation system

1 Introduction

Affected by factors such as climate change, population growth, human activities, and the accelerated urbanization process, extreme disasters occur frequently and suddenly. While causing huge economic losses, they are also accompanied by serious casualties. In particular, typical disaster scenarios such as earthquakes, landslides, and debris - flows have significant characteristics such as strong suddenness, great destructiveness, and wide - spreading influence. Moreover, after a disaster occurs, rescue work often faces severe challenges such as damaged roads, paralyzed traffic, interrupted communication, and blocked information transmission [1]. The SA of affected people is the top priority of emergency rescue work, and rapid, accurate, and efficient SA operations have become extremely important.

The elements of post - disaster rescue of buried and trapped targets are complex. Factors such as spatial distribution, burial depth, medium type, and vital signs all affect the efficiency of rescue. In addition, the complex environment in the affected area also greatly limits the timely entry of rescue workers into the rescue area to carry out operations. The search operations for buried and trapped targets mainly rely on professional

L. Trajkovic et al. (eds.), *Proceedings of the 2026 2nd International Conference on Data Mining and Project Management (DMPM 2026)*, Advances in Economics, Business and Management Research 390,
https://doi.org/10.2991/978-94-6239-689-0_20

equipment such as SA dogs and life detectors, and adopt search strategies from large - scale search, area division to single - building search [2]. However, limited by the scarcity of human resources and the complexity of the disaster scene, the efficiency is often low. Moreover, when facing large - scale disasters, a single SA equipment cannot be competent for diverse SA tasks due to its limitations in perception and execution capabilities [3]. Therefore, the search for trapped people often adopts a joint operation of multiple equipment and technical means. Existing research mostly focuses on specific types of disaster scenarios, and various rescue equipment and means such as radio communication, mobile phone communication, life - detection radar, and demolition tools [4] are used for SA. With the development of science and technology, more and more high - tech and sophisticated equipment is put into the rescue scene. The equipment is easier to operate, more versatile, and has higher environmental adaptability, providing more new - quality productivity for emergency rescue. However, in the face of such a large number of advanced technical equipment with rich functions, how to reasonably and effectively organize the operation sequence and mode to improve the efficiency of SA operations is an important problem that needs to be solved urgently. This paper combines multiple equipment and means, integrates multi - source data information, and establishes a three - dimensional "air - space - ground - human" search operation mode to realize the transformation of the post - disaster search operation mode from the traditional local and decentralized ground - based mode to the all - domain joint mode of "air - space - ground - human" coordination.

2 Current Status of Search Technologies and Equipment for Buried and Trapped Targets

The location of buried and trapped targets mainly uses life - detection technologies, which detect the physiological signals of living organisms and locate the positions of people through two methods: contact and non - contact [5]. Contact - type vital signs sensing technologies mainly use electrodes, sensors, or probes to directly touch the living targets and detect their physiological signals. This method has high detection accuracy, but is limited in application scenarios and scopes due to the length of electrodes and cables. Non - contact vital signs sensing technologies have broken through the above - mentioned constraints. They can detect physiological signals in a non - contact form and penetrate obstacles at a certain distance. They have obvious advantages in detection distance, penetration ability, and application scope, and are more suitable for post - disaster SA of people. According to the principle, this technology can be divided into search technologies based on optical signals, acoustic signals, odor signals, bio - radar, and mobile communication. Various equipment products have been derived based on various search technologies. Table 1 summarizes the advantages and disadvantages of various life - search technologies [6]. By integrating these life - search technologies onto different platforms and conducting comprehensive operational analysis of multiple data in the background, and combining technologies such as computer control and image processing [7-9], airborne life - search equipment and land - based rescue equipment have been derived. Airborne search equipment can break through the limitations of complex ground environments and conduct rapid, large-scale life search at rescue sites, including various types of unmanned aerial vehicles (UAVs)[10-11]. According to different movement forms and functions, land - based rescue equipment can be divided into tracked search robots, wheeled search robots, bionic search robots (snake - like robots), and small - scale rescue robots, etc.

Table 1. Merits and demerits of various search technologies

Technology Type	Advantages	Disadvantages
Based on acoustic signals	It can penetrate metallic objects and is sensitive to slow movements.	It has a limited detection range and cannot detect unconscious victims.
Based on optical signals	It features low cost and low power consumption.	The visible range of the image is relatively narrow, and it cannot be applied to inaccessible areas.
Based on odor signals	It possesses high sensitivity and strong resistance to environmental interference.	It is difficult to deploy in open environments. Mature products for disaster rescue applications are not yet available, and most relevant research is still conducted in laboratories.
Based on bio-radar detection	It features strong penetration capability, high positioning accuracy, and excellent anti-interference performance.	It has limited long-distance detection capability and poor performance in multi-target detection.
Based on mobile phone signals	It provides a signal intensity higher than that of human vital signs, enables large-scale search and localization, and features low cost.	It relies on external base station equipment, and its accuracy is significantly constrained by environmental factors.

3 Characteristics of SA in Typical Disaster Scenarios

Typical disasters such as earthquakes, landslides, and debris flows are highly destructive, cover a wide range of influence, cause enormous losses, and impose high requirements on rescue response and efficiency. This paper analyzes these characteristics from three levels: disaster-causing characteristics, personnel burial environment, and personnel burial distribution, so as to provide basic support for establishing a target-driven multi-source information fusion SA operation method. Specifically, the collapsed buildings caused by earthquakes are widely distributed, large in quantity, and diverse in structural types and collapse forms. Compared with geological disasters, earthquakes are more likely to form survivable spaces, and the probability of life survival is relatively higher. The properties of the burial medium are complex and diverse, mainly including building structural components and daily necessities. Since the collapse form of buildings does not form a tight burial feature, survivors are highly likely to be accessible. In specific time periods or for certain types of buildings, the buried personnel are relatively concentrated. In contrast, the area formed by landslide disasters is relatively small, generally less than 1 square kilometer, which belongs to point-like rescue areas. The survival rate of personnel buried by this disaster is extremely low; except for a few personnel who may be pushed to buildings on the edge, it is difficult for others to form survivable spaces. The main burial materials of landslides (a type of geological disaster) are gravel, including large stones, and the buried depth of personnel is relatively large, ranging from several meters to more than ten meters. The distribution of buildings affected by the impact is relatively scattered, and buried personnel may exist from the point where the sliding materials contact the buildings to the end of the landslide, resulting in a scattered distribution of buried personnel. Debris flow disasters, another type of geological disaster, are mostly linearly distributed along valleys and caused by a sudden increase in water volume in the upper reaches. In addition, the water impact carries stones and trees down the valley, forming an obvious impact path. The disaster area is larger than that of landslides, and buried personnel may exist from the impact point to the end. Moreover, the burial materials have extremely high water content, including a large amount of mud, stones, wood and other substances, which leads to an extremely low survival rate of personnel.

4 Construction of a Search and Rescue System for Buried Targets

4.1 Search and Rescue Task Organization System

The search process for buried targets is mainly divided into four stages: affected area boundary determination – rescue target area zoning – suspected buried life point identification – survivor screening and localization. Affected area determination uses unmanned aerial vehicles (UAVs/swarms) to complete tasks such as disaster area image collection, spatial environment scanning, and mobile terminal communication signal acquisition, so as to construct a disaster area model. In the rescue target area zoning stage, the disaster area is divided into high-risk zones, suspected life zones, and safe passage zones according to the local population density. In addition, odor-signal-based life detection technology can be used to monitor and mark areas with abnormal CO_2/VOCs concentrations. Ground search personnel mark unstable areas to prevent secondary collapses and delineate safe operation boundaries. The suspected buried life point stage aims to determine the location and distribution of potential burial sites, mainly by identifying collapsed or damaged buildings to form preliminary judgment targets, rather than the buried life targets themselves. Survivor screening and localization accurately extract the information of buried personnel based on preliminary judgment targets combined with various signal acquisition data, and finally realize the identification of life targets within the disaster area. The search process for buried targets integrates various searched objects and targets with administrative divisions to form task area zoning at different granularities, as shown in Figure 1.

After destructive disasters such as earthquakes, floods, and debris flows, the detection of buried life targets is a continuous operation process. It mainly includes task assembly, task planning, task instruction transmission, task positioning, operation implementation, and task recovery. Task execution relies on task entities, which are the actors performing target search, including various rescue equipment and task team members. According to different scenarios, they can be aerial UAVs or a detachment composed of multiple low-altitude/ground search equipment. The aerial task entity is mainly UAVs, which carry equipment to perform outline search tasks, complete synchronous collection and processing of mobile terminal signals and image data, and realize burial site extraction. Low-altitude/ground task entities include search equipment carried by vehicles, ultra-low-altitude UAVs, and portable devices. These entities carry out operations at burial sites according to guidance information and collect life signal data.

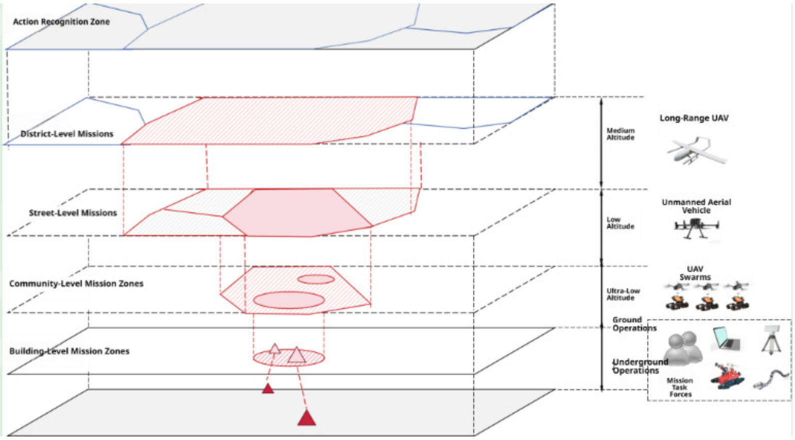

Fig. 1. Relationship between SR process and administrative divisions.

After a disaster occurs, task entities conduct SA operations in accordance with the established plans and instruction requirements. A single task may be undertaken by one or more entities; depending on factors such as spatial scale and equipment capability, a specific area may require the joint efforts of multiple interconnected task entities to complete the search task. When these tasks are performed by the same task entity or a group of task entities, a wave relationship is formed among the tasks. Meanwhile, following the scale principle of from sky to ground and from large to small, after the completion of large-scale search in a specific area, the results obtained will guide subsequent small-scale detection tasks. In this process, a driving relationship is formed between these tasks, as illustrated in Figure 2.

The task organization relationship plays two key roles: on the one hand, it ensures the rational arrangement and orderly organization of the overall regional search work, thereby improving the execution efficiency and coverage of search tasks; on the other hand, it realizes the coordination of SA forces through the collaboration of search tasks at different scales, which further enhances the overall business cycle iteration and information convergence performance of the platform.

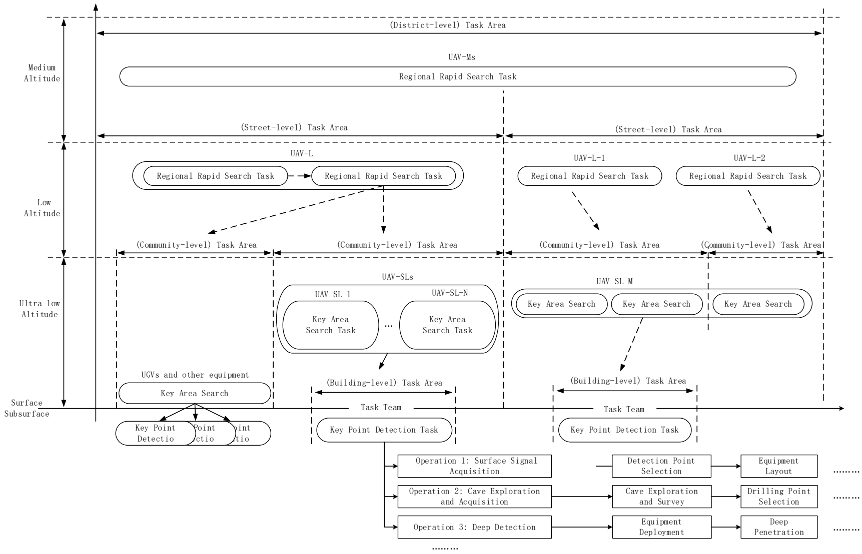

Fig. 2. Organizational relationships of buried target search tasks.

4.2 Multi-source Data Elements and Processing Architecture for Search and Rescue Operations

The information of buried life targets consists of multiple elements, including the spatial characteristics of the buried target, vital signs of the target, burial medium of the target, and target positioning. Due to the harsh disaster environment and the particularity of buried targets, a single technical method can hardly meet the requirements for rapid acquisition of all such element information. Constrained by technology, scenario and other factors during operations, the acquisition of these elements usually relies on diverse means such as remote sensing, aerial photography, data provided by operators, on-site equipment operation, etc. The involved multi-source data mainly include the following categories:

(1) Image data: Visible-light image data of the disaster area obtained by remote sensing, aerial photography and other means. Artificial intelligence and other technologies are used to extract disaster information and related objects from such data;

(2) Infrared data: Infrared data of the disaster area obtained by remote sensing, aerial photography and other means. Based on artificial intelligence and the characteristics of different types of objects, various disaster information in the affected area is extracted;

(3) Communication signal collection data: Mobile phone signals over a wide area of the disaster area are collected by acquisition equipment. Personnel location information extraction and identification of personnel gathering areas are realized based on these data;

(4) Disaster data: Disaster information obtained from emergency management departments and other professional departments, which is used to mark the location, level and impact scope of on-site damage points;

(5) Life signal collection data: Data returned from scanning personnel information inside specific buildings and spaces using active perspective radar equipment for large-range, large-burial-depth and high-precision life detection;

(6) Basic geographic data: Information providing basic landforms, building distribution, population distribution, key target buildings and facilities in the disaster area.

During disaster life target SA missions, data processing and refinement are required according to the characteristics of different types of data. A fusion processing framework is built on the basis of multi-source data aggregation, as shown in Figure 3. The framework mainly includes a clue extraction layer, a preliminary judgment layer, a fusion processing layer and a target recognition layer.

Clue extraction layer: It is mainly composed of a raw disaster database, a disaster information extraction database and a disaster clue database, among which the disaster clue database serves as the output result and external service node of this layer. During the incremental update process, image data and third-party disaster data are exchanged and stored in the local raw database. Meanwhile, after information extraction, the affected point information is verified and encapsulated to form complete disaster information extraction results, which are archived in the disaster information extraction database. Then, the currently incremented disaster information extraction results are horizontally fused with historical records in the disaster clue database, and the generated results are uniformly stored in the disaster clue database.

Preliminary judgment layer: It is mainly composed of a basic geographic database and a preliminary result database, among which the preliminary result database serves as the output result and external service node of this layer. During operation, building damage status is identified based on underlying clues combined with basic geographic data retrieved from the emergency management department's own system, thereby forming a building collapse identification result set. These results are encapsulated, stored and maintained in the preliminary result database, providing necessary data support for upper-layer burial point identification. Meanwhile, combined with basic geographic data, a continuous status tracking mechanism is established for important building objects to meet the requirements of disaster rescue and emergency disposal.

Fusion processing layer: It is mainly composed of a burial point target database and a raw mobile phone signal database, among which the burial point target database serves as the output result and external service node of this layer. Mobile phone signal distribution data covering a wide area of the disaster area, collected by UAVs, ground vehicles, portable devices and other means, is aggregated and stored in the local raw database. On this basis, spatiotemporal clustering is performed on the mobile phone signal distribution data, which is then vertically fused with data in the preliminary result database to form confirmed (buried) targets and to-be-inspected targets. After time-series verification, newly added targets are classified and stored in the corresponding databases.

Target recognition layer: It is mainly composed of a confirmed target database, a to-be-inspected target database and a raw radar scanning database. On the one hand, the basic status of each target in the confirmed target database of this layer is maintained according to underlying processing results. On the other hand, a task-driven mechanism is established for to-be-inspected targets, guiding UAVs to conduct precise search on buried points with unknown status through radar scanning. The collected radar data is aggregated in the local raw radar scanning database. These data are vertically fused with the underlying burial point database to update and maintain corresponding target information.

Based on layered data fusion processing, the above framework constructs a data production–supply mechanism driven by targets. Horizontal fusion realizes the processing of multi-source homogeneous disaster data, and vertical fusion realizes the integration of heterogeneous disaster data, ensuring complete extraction and correct aggregation of target information. In this process, a target discrimination mechanism is established considering the inherent limitations of different data types, and multi-method cross-validation is realized through target-driven mode to guarantee the integrity and accuracy of disaster information. Meanwhile, a polling detection mechanism is established around specific databases in the framework to track and monitor the status changes of various objects, ensuring data timeliness and realizing full-life-cycle target tracking and status maintenance.

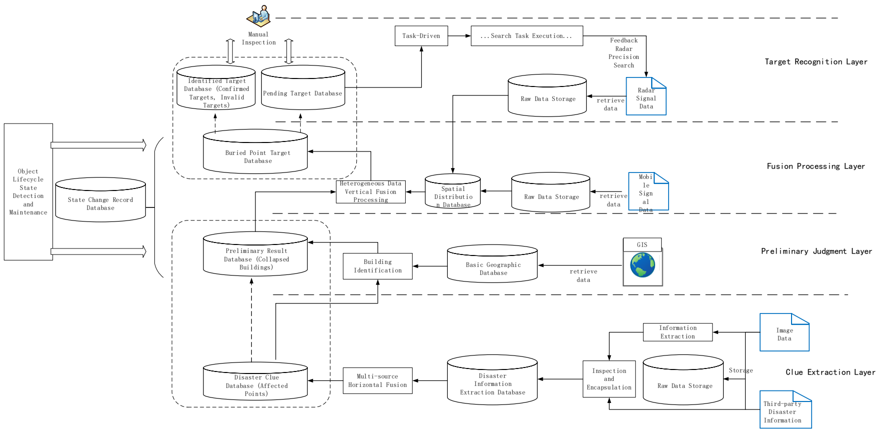

Fig. 3. Multi-source heterogeneous data processing frameworks

4.3 Construction of a Service Organization System for Search and Rescue Operations

Post-disaster personnel search and rescue operations consist of a series of businesses with complex internal and inter-business relationships of correlation, driving and synchronization. It is necessary to construct a search and rescue dispatch platform with decision-making, command and dispatch capabilities to improve collaborative organization efficiency. Meanwhile, focusing on the search, acquisition, identification and positioning of buried life targets, and based on information convergence, the platform realizes a double-loop driving relationship between data aggregation and task operations. With reference to the "Observe-Orient-Decide-Act" (OODA) principle, a space-air-ground-human integrated three-dimensional search organization architecture is established. As shown in Figure 4, the overall business architecture consists of several stages:

Post-disaster Response: In the daily operation process, the platform receives disaster information released by the upstream disaster information system in accordance with business specifications. Upon obtaining incident alarm information and linked command instructions, the platform activates the response mechanism. First, it uses disaster assessment results and operators' communication big data to analyze and evaluate the disaster-stricken area scale and macro-distribution situation. After the search and rescue operation is launched, each task subject arrives at the scene in accordance with task instructions and completes on-site deployment, launch and other actions.

On-site Operation: During the on-site operation, in accordance with the search and rescue arrangement plan, the command center guides medium and high-altitude unmanned equipment to conduct rapid scanning and search work in the disaster-stricken area, realizing initial data collection and information extraction. On this basis, iterative analysis is carried out on a macro scale in combination with disaster information.

Task identification zones are established based on regional administrative divisions and the distribution of various clues. On this basis, regional operation decisions are made. After completing the above work, the equipment remains in the air in accordance with resource status and overall scheduling requirements to carry out continuous situation monitoring and communication support.

Key Area Close-Range Search: Low-altitude and ultra-low-altitude UAVs equipped with search equipment (life signals, electronic information signals, transient electromagnetic, photoelectric scanning, etc.) conduct close-range and precise searches at designated locations. In this process, task subjects are guided to perform operations in sequence in accordance with the regional task arrangement plan. During the implementation, the identification scope is gradually converged based on the analysis conclusions of the collected data. At the same time, it provides support for the subsequent decision-making on the investment of ground forces.

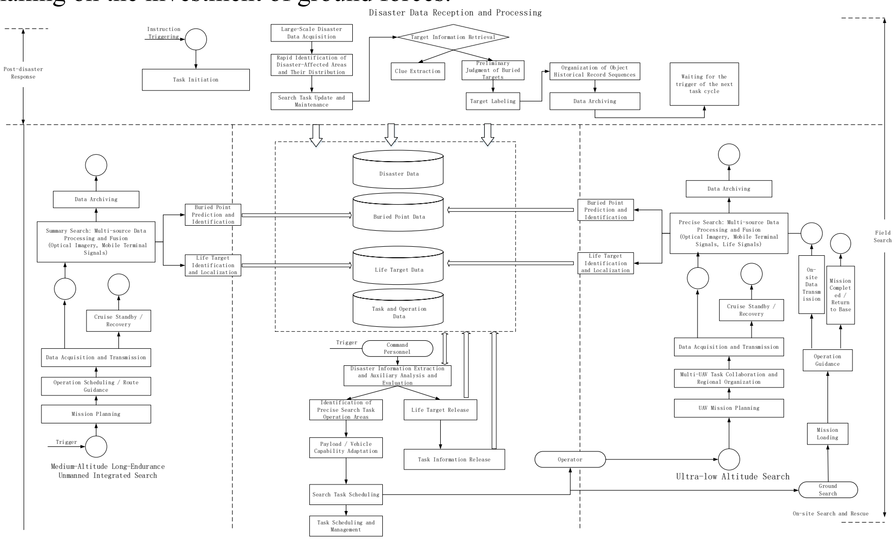

Fig. 4. Organizational of air-space-ground-human SR operations.

5 Scenario Verification

Based on the rapid search and rescue operation system proposed in this paper, Badong National Observation and Research Station of Geohazards was selected to establish a simulated environment for searching buried personnel. Simulated life signal target instruments were deployed at the simulated burial positions in the demonstration site, with the target burial depth set to 45 meters. Based on the developed prototype of the life search service platform, the entire operation process was demonstrated, as shown in Figure 5.

Fig. 5. SA Operation Demonstration

Firstly, the UAV rapid 3D modeling system was used to generate high-precision 3D images of the test site, so as to determine the scope of the rescue operation surface. Secondly, based on 4G and 5G communication signals, the scale of personnel with buried mobile phone terminals was estimated, and the analysis of the personnel scale within 5 km was completed within 30 minutes. Then, within the scope of buried terminals analyzed based on mobile phone signals, UAVs were mounted with mobile phone terminal search equipment. The test results showed that when the detection depth was ≤ 10 m, the error was ≤ 3 m. Finally, within the scope scanned by the intelligent terminal, UAVs were mounted with transient electromagnetic or life detection radar equipment to scan cavities and accurately locate buried life targets, as shown in Figure 6. The detection results showed that the depth was 48 m with an error of 3 m.

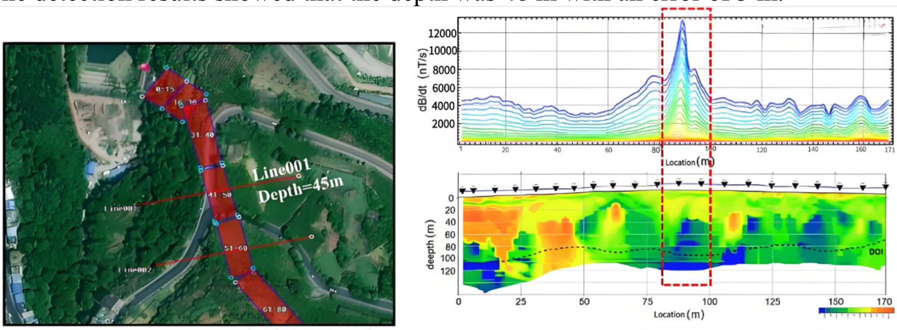

Fig. 6. Demonstration Detection Results of Buried Targets

6 Conclusion

Based on the analysis of the SA characteristics of typical disaster rescue scenarios such as earthquakes, landslides, and mudslides, combined with the current research status of the development of buried target search equipment, and in accordance with the characteristics of large disaster-stricken areas, complex scenarios, and tight time constraints, a multi-layer cross-domain three-dimensional search method using the "space-air-ground-human" integrated equipment is adopted to realize data-driven coordination of manned and unmanned equipment across the entire disaster area, optimize the organization method of SA tasks, and improve the application efficiency of search work.

The ultimate goal of disaster rescue is to accurately obtain information on trapped and buried personnel. A precise personnel search operation organization method based on multi-source information fusion is designed, which relies on the aggregation of data collected in a wide area to form a full-coverage panoramic data set. On the basis of specific types of data, analysis and information extraction are carried out to form clues of buried targets. According to the temporal and spatial constraints provided by the clues, the status of building objects in the data set is extracted, collapsed or damaged building objects are identified, and preliminary judgment targets are formed. On the basis of the preliminary judgment targets, combined with various signal collection data, the accurate extraction of buried personnel information is realized, and multi-source detection fusion is used for precise positioning. Finally, the identification of deterministic targets in the disaster area is formed, and the SA efficiency of buried personnel after disasters is improved.

Acknowledgment

Funding: This work was supported by the National Key R&D Program of China (2023YFC3011505) .

References

1. HANG Qi. “Research on emergency collaborative decision making based on earthquake rescue”. Shen Yang Aerospace University,2023.
2. Na Gao,Jin Yan, et. “Research on Life Detection Strategies for Extremely Large Earthquake Disasters”.DRR Outlook, 2025,(02):59-63.
3. ZHAO Chenwei, Multi-robot collaborative intelligent search and rescue and emergency networking optimization[D], Dong Hua University,2024.
4. LIU Hao, SHI Fuli, LUO Lei , et al. “Demand prediction of earthquake disaster rescue equipment based on ISSA-BP”, China Safety Science Journal, 2025,vol.35(S1),pp.246-251.
5. Yu Jing, Yusen Cao,et al. “Research Status and Development of Non-Contact Life Detection Technology”,China Medical Devices, 2021,vol 36(06),pp.1-4.
6. Joret, Ariffuddin, et al. “Human detection techniques for search and rescue of trapped victims under debris: A review.” Evolution of Information, Communication and Computing System,2022, pp.54-65.

7. Aliff M, Amry I S, Yusof M I, et al. Development of smart rescue robot with image processing (iROB-IP)[J]. International Journal of Electrical Engineering and Technology, 2020, 11(9): 08-19.
8. Dadwhal Y S, Kumar S, Sardana H K. Data-driven skin detection in cluttered search and rescue environments[J]. IEEE Sensors Journal, 2019, 20(7): 3697-3708.
9. Joseph J, Berchmans N, Varghese M R, et al. Arduino based automatic human seeker robot for disaster management[C], 2019 2nd International Conference on Intelligent Computing, Instrumentation and Control Technologies (ICICICT). IEEE, 2019, 1: 770-773.
10. Ajith, V. S., K. G. Jolly, and K. Vidhya. "Intelligent task scheduling in multi uavs during the flood relief operation." 2023 International Conference on IoT, Communication and Automation Technology (ICICAT). IEEE, 2023.
11. Khattab, Omar, et al. "Design and implementation of a smart earthquake rescue robot to enhance rescue operations." Scientific Reports (2025).