A Few Thoughts on the Integrated Space-Air-Ground Emergency Rescue Communication Command in China

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April 14, 2023

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Abstract: With the rapid development of remote sensing, geographic information (GI), artificial intelligence (AI) and other technologies, China is continuously strengthening emergency rescue innovation and numerous breakthroughs related to emergency rescue technologies and equipment which have been made through the National Key Research and Development Program. This paper first proposed and illustrated the concept, connotation and characteristics of integrated space-air-ground emergency rescue communication command from the perspective of mapping and geographic information, and then analysed the challenges faced by the integrated space-air-ground emergency rescue communication command in China. Subsequently, a space-air-ground emergency rescue command theoretical system is introduced by combining broadband emergency communication, accurate acquisition of real-time disaster information, disaster situation and scenario projection, emergency communication command services, and resilient emergency rescue command. The proposed integrated space-air-ground emergency communication and command design concept will be applied for China's disaster emergency rescue and command in the future to comprehensively improve the emergency rescue communication and command capability in China.

Keywords: Emergency rescue, communications command, integrated, geographical information systems, cartography

1. Introduction

With the frequent occurrence of extreme climate events and fast urbanisation, the frequency and impact of natural disasters are increasing, which seriously affect the sustainable and stable development globally (Alexander, 2018). China is one of the most affected countries in the world with geological, meteorological, marine, biological, ecological and environmental disasters. For example, in the last 25 years, an annual average of about 400 million people have been threatened in China, and lead to over 4,000 deaths and direct economic losses of over RMB 230 billion. Accurate access to disaster information, efficient command and allocation of emergency relief resources are significantly crucial to people's lives and property.

Recent advance of theories and technologies from remote sensing, geographic information, mobile communication, artificial intelligence and big data are able to provide early warning and monitoring of disasters, thus providing key information through emergency communication networks. This helps to generate emergency plans to make auxiliary decisions and command on-site rescue. Remote sensing technology can provide large-scale multi-temporal disaster data which is combined with geographic information, artificial intelligence and big data technology to carry out disaster situation deduction and auxiliary decision-making command. Furthermore, mobile communication technology can provide effective information transmission for emergency rescue (Berlyand et al., 2018; Cova, 2005). With these key technologies and theories, many countries have continued to strengthen emergency rescue innovation. For example, the US has implemented the Disaster Emergency Response Technology Innovation Grant Program and Disaster Mitigation Challenge Science and Technology Action Plan, and Japan has implemented The Action Plan for the Toughening of the National Territory. China has also implemented the National Key R&D Programme "Major Natural Disaster Prevention and Control and Public Safety" special project, etc. Although a series of breakthroughs in emergency rescue theory and equipment have been made, there exist many challenges such as the lack of command coordination mechanism, low level of intelligent decision-making and complex correlation of response mechanisms. In terms of disaster emergency communications, companies such as Sinosat has developed broadband self-assembly networks, vehicle-mounted mobile communications, airborne satellite communications, etc. However, it still lacks independent networking, multi-mode coordination and rapid deployment of high-bandwidth communication support equipment, which makes it difficult to quickly and effectively guarantee on-site monitoring and rescue command under extreme conditions such as public network disruptions and complex terrain. In terms of disaster scene information extraction and intelligent discrimination, a series of provincial disaster simulation systems and monitoring equipment have been developed, but few equipment can be rapidly deployed on site to support wide-scale accurate monitoring and evaluation, and the integration of space-air-ground network collaborative monitoring is insufficient. For disaster situation analysis and simulation projections, although some scenario evolution and deduction models have been initially generated and applied, there are still problems such as insufficient multi-dimensional refinement of situation extrapolation on a spatial and temporal scale as well as ineffective dynamic generation capability and intuitiveness of knowledge-driven and scenario extrapolation rescue plans. When it comes to digital command operations for rescue command, the National Engineering Laboratory for Integrated Command and Dispatch Technology and the National Emergency Mapping Center have begun to promote the intelligence of traditional command and dispatch elements and means. Emergency, and public security and military departments have built information platforms for emergency management intelligence collection and command and disposal. However, they are unable to establish integrated command platforms based on unified spatial and temporal benchmarks, integrated disaster intelligence all-source perception, holographic digital base, and communication and decision-making command fusion, thus making it difficult to support information symmetry, seamless integration and efficient coordination among emergency rescue forces (Mcloughlin, 1985). In summary, China needs to further explore the emergency rescue communication and command system in a systematic manner in terms of theory, technology and equipment.

This paper aims at proposing an integrated space-air-ground emergency rescue communication and command design to address the problems of imperfect theory of emergency rescue communication and command, low persistence of communication networks, insufficient monitoring and discriminating capability, insufficient integration of situational deduction and low efficiency of multi-level cross-domain combat command in China's current emergency rescue communication and command system. The design focuses on modern emergency rescue command theoretical system, emergency communication technology and equipment under extreme conditions, rapid acquisition of disaster site information and intelligent identification equipment, disaster situation evolution model and scenario projection technology, holographic digital combat command platform and other key technologies and equipment. This will provide significant theoretical guidance for the life course of disaster emergency rescue in China.

2. Concept and feature of the integrated space-air-ground emergency rescue communication command

2.1 Concept of integrated space-air-ground communication command for emergency response

The current emergency communication command mainly relies on communication infrastructure and is supplemented by emergency communication vehicles as well as the use of satellite networks, shortwave networks and trunking communication networks to provide the same communication services. The wireless self-organizing network technology has not been fully utilized and drawn attention, and the degree of integration of various communication technology means is not enough. The limited coverage and poor network transmission capacity, self-adaptive ability and tenacity cannot provide all-round and reliable emergency communication guarantee for major disasters and accidents. At the same time, the degree of portability, miniaturisation and autonomy of emergency communications equipment is insufficient. This poses difficulties for the rapid and large-scale deployment of emergency communication networks. The integrated space-air-ground emergency communication command is designed to use advanced satellite communication technology, aerial unmanned platform communication technology, ground-based self-assembling network technology and public network technology, etc. Through unified intelligent design and efficient network fusion technology to build a seamless cross-regional inter-departmental communication network integrated with the sky and ground, a wide range and high speed of reliable communication guarantee, disaster situation and scenario projection and decision-making for emergency rescue can be provided. The network will quickly provide reliable communications, disaster situational and situational rehearsal and decision-making services.

2.2 Features of an integrated space-air-ground emergency rescue communication command

In the face of heavy and mega natural disasters resulting in large area and long time public communication network interruptions, "communication islands", space-air-ground integrated emergency rescue communication command is a highly informative and intelligent system under the guidance of advanced emergency rescue command theoretical system. A high-speed, high-bandwidth emergency communications solution to replace the terrestrial public communications network is needed to ensure the smooth flow of communications networks for important post-disaster relief work. The characteristics of major natural disasters dictate that emergency relief communications equipment needs to have the following characteristics:

a) Space-air-ground integration: air-based communication networks consist of high-, medium- and low-altitude drones where low-altitude airships can cover 800-1,000 square kilometres of major affected areas, and mobile communication systems composted of ground-based, large-bandwidth self-organising communication equipment. This can be rapidly deployed to form networks and quickly replace some of the public network's communication capacity, taking on the heavy responsibility of emergency communications.

b) Diversification and small size: communication command equipment support cross-domain emergency relief based on multiple subjects and multiple sources of information, including portable ground satellite communication equipment and antennas, unmanned airborne/vehicle-mounted lightweight integrated satellite communication equipment, handheld and backpacked man-portable light and small ground self-assembling network communication equipment, airborne small integrated self-assembling network communication equipment, etc.

c) Human-machine collaboration and intelligence: embodied in the rapid acquisition of disaster situations, information transmission and command end of the intelligent integration of data processing and knowledge-driven disaster situational analysis models support the integration of space-air-ground collaborative communication command.

3. Challenges of integrated space-air-ground emergency rescue communications command

3.1 High throughput emergency communications in complex environments

Major natural disasters cause huge changes in geography, especially in complex urban environments where conventional communications often have difficulty in covering collapsed buildings or underground, such as areas of the metro. Damage to electrical installations, disruptions to public networks and damage to roads also make conventional communication facilities unable to meet the demanding needs of emergency response. For example, large communications equipment is often unable to accompany a single soldier into complex environments, creating a need for miniaturisation of communications equipment. In addition, information transmission rate is also critical to the delivery of disaster information and decision-making. How to break through multimodal, miniaturised, full-coverage emergency communications has become a difficult and hot topic.

3.2 Multi-platform collaborative disaster information acquisition and fusion

Space-based remote sensing equipment often allow for large-area and multi-temporal acquisition of disaster damage information in the area the disaster occurred. Although geostationary remote sensing satellites can achieve real-time monitoring, they usually have a low spatial resolution, which makes it difficult to meet the high-resolution disaster information extraction. LEO satellites have higher spatial resolution but also have the problem of re-entry time that the satellites cannot monitor the same area for a long time. Although space-based unmanned aerial vehicles (UAVs) with remote sensing equipment can continuously monitor the disaster area, they cannot achieve full time phase of regular early warning monitoring for disaster-prone areas, especially where is under complex environmental conditions such as rain, fog and night. Still, there are some problems by using UAVs such as insufficient integration of sky-ground network cooperative monitoring, low intelligent level and poor timeliness of disaster information acquisition. Therefore, there is an urgent need to expand new information acquisition platforms for regular monitoring of disaster-prone areas. Furthermore, the fusion of multi-source space-based and air-based remote sensing data can relatively overcome the above problems, but the precise spatiotemporal data fusion is a major difficulty in the current research (J. Liu et al., 2021).

3.3 Multi-factor-driven model of disaster posture evolution

The traditional "predict-respond" model of disaster response is ineffective because major natural disasters are characterised by continuous evolution and interconnected processes, and are the result of interactions between the system and external society, which makes the understanding of the evolution of disasters complex and uncertain. Since natural hazards generate, erupt, develop and weaken throughout the entire process of extinction, a variety of complex scenarios are derived secondarily, presenting characteristics and attributes that correspond to different scenarios and are "scenario-dependent". The "scenario-response" theory system has been introduced in recent years which is based on the changing scenarios during the development of an event, and can be used to generate and organise emergency decisions in real time, effectively reducing uncertainty. Meanwhile, situational evolutionary projection is an important part of the "scenario-response" type of natural disaster decision-making system. It takes a scenario-based disaster event scenario as input, combines the event scenario with the projection strategy, analyses the development trend of the incident and projects future scenarios. The current challenges in natural disaster scenario development include complex chains of derivation, diverse driving factors and complex evolutionary mechanisms, thus making it difficult to clarify the underlying characteristics of disaster occurrence and the spatiotemporal triggering effects of the contributing factors, as well as to sort out the triggering relationships between multi-hazard hazards and their coupling and superposition effects on a spatiotemporal scale.

3.4 Cross-departmental command based on massive amounts of information

Disaster emergency command involves interdisciplinary and cross-sectoral multi-subject cooperation. Emergency command theories include group decision, collaborative decision, self-synchronization, etc. In terms of intelligence decision, there are many methods such as trend analysis, expectation analysis and group analysis. The incident command system proposed by the United States is the current international mainstream command system architecture, covering the common construction ideas and functional structure methods of the emergency rescue command system (Lee & Edmondson, 2017). Chinese government agencies and research institutes have also carried out research in this area, but have mostly focused on emergency planning and emergency communications(M. Liu, Yang, & Gui, 2019; Wang, Yang, Gao, Li, & Zhou, 2016), and have not yet formed a systematic, multi-level, standardised, cross-departmental military-to-military collaborative system architecture. There is an urgent need to study a more suitable theoretical system of emergency rescue command to support the construction of a modern command system and guide multi-subject, multi-source information and cross-domain emergency rescue. In addition, the construction of command platforms is also crucial. Digital combat command based on all-source intelligence access, spatio-temporal unified benchmarking and battlefield rapid twinning is the current development trend of emergency command.(Fan, Zhang, Yahja, & Mostafavi, 2021; Huang, Cervone, & Zhang, 2017).

4. Integrated space-air-ground emergency rescue communication command design

4.1 General framework design

In view of the imperfect theoretical system, the low persistence of the communication network, the insufficient monitoring and discrimination capability, the insufficient integration of the situational projection model, the low efficiency of multi-level cross-domain combat command and other problems faced by the space-air-ground integrated emergency rescue communication command, numerous research have been focused on the systematization of modern emergency rescue command theory, emergency communication protection under extreme conditions, multi-sensor collaborative monitoring and intelligent discrimination, scenario projection rescue plan generation, "sensing-communication-decision-command" integrated scheduling and other practical needs. To address scientific issues such as the theory of all-factor modular emergency rescue command and coordination, the performance influencing factors and interaction mechanism of sky-ground heterogeneous fusion communication networks, the spatiotemporal evolution characteristics of disaster emergency monitoring targets and the response mechanism of multiple rescue elements, breakthrough have been made in the convergence and optimization of heterogeneous space-air-ground emergency communication networks, the electromechanical and thermal integration design of lightweight broadband satellite communication equipment, rapid scanning and intelligent assessment of high points of disaster damage in large areas, rapid and high-precision positioning of BeiDou stars/ground in the disaster emergency environment, knowledge graph-driven model construction of disaster situation evolution, dynamic scenario-based emergency digital plan generation engine, multi-model integration of all-source emergency intelligence generation, integrated dispatching of holographic real-world combat command and other key technologies. The research focuses on modernising the theoretical system of emergency rescue command, emergency communication technology and equipment under extreme conditions, rapid acquisition of disaster site information and intelligent identification equipment, disaster situation evolution model and scenario projection technology, and research and development of a holographic real-world digital operational command platform. The general framework design is shown in Figure 1.

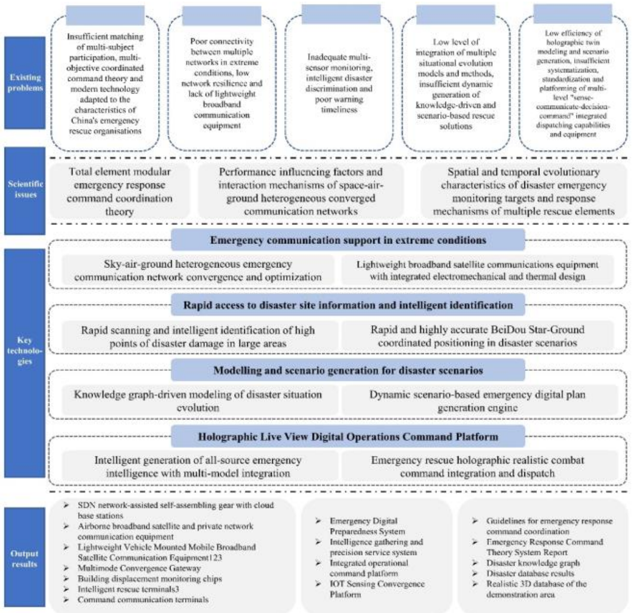


Figure 1. General design framework

4.2 Space-air-ground integrated high-throughput emergency communication technology and equipment

In response to the challenges of emergency communication protection under public network failure, road damage, power disruption, complex terrain and adverse weather conditions during forest and grassland fires, earthquakes and geological disasters, many companies designed the integrated space-air-ground network architecture for emergency communication scenario awareness and proposed the intention-driven space-air-ground integrated network architecture and optimization method under extreme conditions. The intention-driven integrated space-air-ground heterogeneous emergency communication network technology and self-assembled network equipment for high-capacity long-distance transmission technology are adopted, and multimodal self-adaptive convergence gateways, intention-driven network resource allocation and routing configuration optimization software platforms, software-defined network-assisted self-assembled network equipment and cloud base stations are developed independently. There are also some research on low-power transmission technology for high-throughput satellite communications, independent development of lightweight, low-power airborne and vehicle-mounted satellite communications equipment. Based on the above key technologies, a new generation of space-ground integrated broadband emergency communications technology and equipment can be formed

4.3 Real-time disaster information precision acquisition technology and equipment combined with solid and mobile

To address the problem of multi-sensor collaborative monitoring and disaster intelligence discrimination, the UAVs and airship are used for high point monitoring with the cooperation of fixed and movable, and multi-sensors such as Beidou positioning, high-definition video, LiDAR, thermal infrared camera. Breakthroughs in real-time multi-source data matching and fusion and holographic perception modeling technology can solve the problems of limited range and low perception accuracy of dynamic and complex disaster site monitoring. Combining the theory of artificial intelligence with real-world 3D technology, numerous methods are proposed for not only intelligent extraction for disaster damage information but accurate detection for 3D change. At the same time, quantitative evaluation model of disaster damage and risk based on multi-source information is constructed with the aim of realising intelligent assessment and active early warning of disaster. With the above key technologies, integrate emergency communication terminals can been developed to provide equipment for precision acquisition of disaster information and disaster intelligence discrimination.

4.4 Dual "data-knowledge" driven situational and scenario-based techniques

To address the problems of incomplete disaster scenarios, poor knowledge and a single method of deduction in the process of "prediction-response" to static scenarios, a knowledge-data-driven disaster evolution model database is built, and a multi-category typical disaster knowledge graph covering the whole life cycle of "conception - occurrence - development - evolution - disappearance" of typical disaster events is constructed. The research is based on knowledge inference and recommendation of disaster scenario reproduction technology, and the use of machine learning algorithms to analyse the multiple potential trend targets and evolution probabilities of disaster events driven by the social-natural environment, and through model integration, a scenario generator is developed that can perform rapid extraction of scenario elements, automatic measurement of inference indicators, and real-time calculation of the inference process. This could support the rapid identification of disaster factors, accurate response to disaster status, and comprehensive prediction of disaster trends in the emergency rescue process, as well as assist in the preparation of emergency rescue plans and simulation of emergency decision-making solutions.

4.5 Emergency communication command service technology based on realistic 3D platform and multimodal terminal

In order to meet the needs of digital holographic battlefield environment and standardization of multi-level cross-domain communication and command equipment system, research on multi-source heterogeneous data fusion technology, intelligent three-dimensional model construction technology and scene model lightweight and efficient technology are made to build holographic real-world information base, realize real-world three-dimensional standardized expression and high-performance adaptive expression of massive information. There are some research on emergency rescue situation distribution and sharing, multi-format command and control information conversion and fusion processing technology. Research and development of command platforms and multimodal communication terminals for the digital battlefield is to achieve integrated integration of perception, communication, decision-making and command and efficient cross-domain collaboration through the standardization of protocol interfaces, functional module components and virtualization of the operating environment, to achieve integrated integration of perception, communication, decision-making and command and efficient cross-domain collaboration.

4.6 A combined human-machine-data theory system for resilient emergency rescue command

To further enhance the resilience and science of the emergency rescue command system to deal with a wider range of threats, some studies existed such as integrated emergency management theory and other related cross-disciplinary theories, the distillation of modern emergency rescue elements, the analysis of the decision-making behaviour patterns of decision-makers in specific scenarios, and the construction of a combined human-machine-data emergency rescue equipment system application model and command coordination model. The mechanism of emergency rescue command coordination is explore to reveal the characteristics of disaster systems and response systems and the laws of interaction. Analysis on the deployment of emergency forces and the mechanism of coordination between forces of different levels and subjects, such as the military, fire, public security and society are also explored. Meanwhile, emergency command coordination strategies are optimised based on the theory of emergency rescue command system, studies on emergency command capability measurement based on "scenario-response" propose emergency action plan preparation methods, innovates modern emergency rescue command theory systems from top-level design to provide on-site guidance and cover all levels of emergency command, all departments and subjects for realizing the integration and application of command systems, equipment systems and data systems.

5. Preliminary exploration of integrated space-air-ground emergency rescue command

Space-air-ground integrated emergency rescue communication command focuses on typical natural disaster emergency rescue scenarios, based on the characteristics of integrated emergency rescue communication command, through digital disaster scene holographic perception and scene twin construction, multi-mode command communication terminal integration, all-source intelligence-driven communication decision command integration and other technologies, and initially realizes intelligence collection and analysis and services based on multi-source heterogeneous information fusion and online emergency mapping based on disaster scenario and data integration, integrating key technologies such as geological disaster displacement monitoring equipment, regional geological disaster intelligence services, rapid emergency communication network optimization, large-scale complex disaster scenario fusion and enhanced visualization. Figure 2 shows the geohazard displacement monitoring equipment, and Figure 3 shows the typical geohazard location monitoring. Figure 4(a) shows the resulting map of communication signal tower distribution with Tyson polygon optimization, and Figure 4(b) shows the schematic diagram of communication capacity coverage of the emergency communication base station network.

Figure 2. Geological hazard monitoring sites

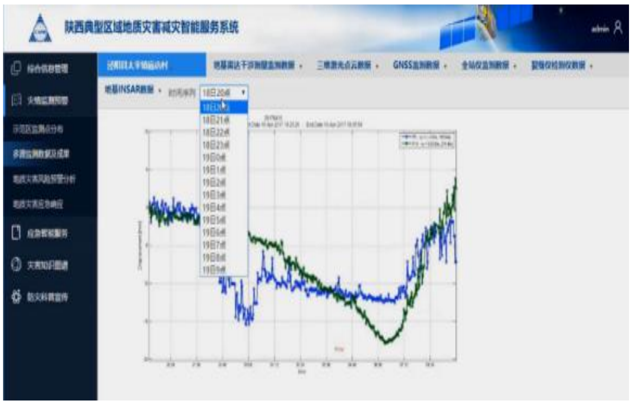
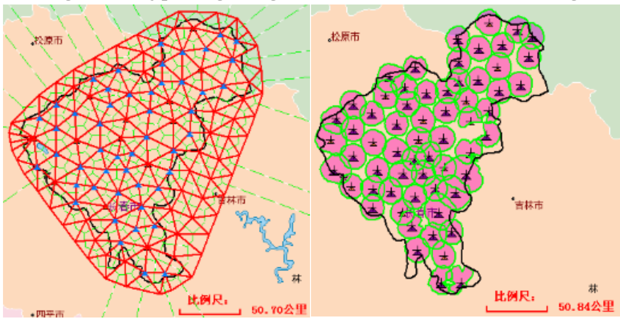


Figure 3. Typical geological hazard location monitoring



(a) (b)

Figure 4. (a) Tyson polygon optimized signal tower distribution, (b) Signal Tower Coverage

6. Conclusion

Emergency rescue is an important service for emergency mapping and disaster prevention and mitigation research. This paper reflects on the integrated space-air-ground emergency communication command in China from a multidisciplinary perspective by refining the concept and characteristics of the integrated space-air-ground emergency communication command and focusing on such features as diversification, lightness, intelligence, spatial and temporal accuracy, human-aircraft coordination and sky-ground integration, etc. It exemplifies the challenges and designs solutions for an integrated space-air-ground emergency relief communication command in terms of disaster emergency communication, all-round access to disaster information, disaster situation projection, emergency communication command services and command system. The important role that geographic information and mapping can play in the space-air-ground integrated emergency rescue communication and command. Finally, the preliminary implementation of a prototype space-air-ground integrated emergency rescue communication and command system is introduced to promote the in-depth development and application of integrated disaster reduction and intelligent service technology and provide new ideas for the construction of China's emergency rescue system and equipment.

Funding: This work was supported by National Key Research and Development Pro-gram of China under Grant Grant No. 2022YFC3005705 and the Basic Research of CASM under Grant No. AR2310.

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