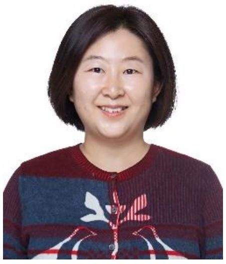
Research on Demand of Intelligent and Unmanned Emergency Rescue Equipment for Typical Geological Disasters



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Abstract

By analyzing the characteristics of typical geological disasters such as chain-breaking, frequency, serious damage and emergency rescue, this paper extracts the demand for rescue equipment from emergency rescue operation scene, mainly including disaster detection, main operation, assistant operation, transport and delivery, positioning and communication. Because of the complex rescue environment, emergency rescue equipment also needs the autonomous driving and intelligent operation in hazardous environment to improve the rescue efficiency and ensure the life and safety of rescuers. To promote the development and performance evaluation of intelligent and unmanned emergency rescue equipment, a testing and evaluation index system of intelligent and unmanned emergency rescue equipment is built based on the analysis of intelligent and unmanned demand for equipment in emergency rescue scenarios of typical geological disasters. This index system includes four layers of target, criteria, feature, and index, which represents the core functions and performance of intelligent and unmanned emergency rescue equipment objectively and scientifically and provides reference and basis for subsequent testing and evaluation research.

Keywords: Typical Geological Disasters, Emergency Rescue Demand, Intelligent and Unmanned Emergency Rescue Equipment, Testing and Evaluation Index System

1. Introduction

China is one of the countries with the most serious geological disasters in the world. As there are many mountainous areas, complex terrain and special geological structure, potential geological disasters are widely distributed. According to the preliminary statistics of the Ministry of Natural Resources of China (2021), 7840 geological disasters occurred in China in 2020, including 4810 landslides, 1797 collapses and 899 debris flows. These disasters caused 18,000 casualties and direct economic losses of 5.02 billion RMB. Influenced by frequent occurrences of strong earthquakes and extreme meteorological events, geological disasters in China have become more frequent in recent years. The number of geological disasters in China increased by 26.8% in 2020 compared with 2019.Earthquake, debris flow, barrier lake and other disasters are often interacted and easy to form a disaster chain, so that disasters are superimposed and more destructive.
After disasters, emergency rescue equipment can help responders to carry out efficient rescue and reduce unnecessary casualties. The traditional emergency rescue equipment is mostly manual operation, lacking the function of intelligent operation and autonomous driving in hazardous environments. Rescue efficiency of traditional equipment is inefficient, which easily threatens the life and safety of rescuers and cannot meet the demand for rescue at the disaster. In the emergency disposal of Baige Weir Lake on November 3 of Jinsha River in 2018, it is difficult for large engineering machines to be transported to the site and carry out operations due to blockage and damage of the road to the weir body and helicopter load not meeting the requirements. Moreover, the existing emergency rescue equipment is not intelligent enough to meet the goal of safe and efficient rescue (Wang Wenke and Huang Xianlong, 2018).
In recent years, to maximize the replacement of rescue workers and improve rescue efficiency, many countries have carried out research on combining emergency rescue equipment with new technique, which enables the equipment to have intelligent control strategy, accurate environmental perception, self-learning, and self-adaptation in emergencies. There are many kinds of emergency rescue equipment. At present, the main types of equipment which have been carried out intelligent and unmanned research are engineering machinery (ZHANG Jie, 2020; DERLUKIEWICZ D, et al., 2016), small rescue robot (Yu-tan Li, et al., 2016; Li Yixiang,2013), and large equipment delivery platform (Craftsman Engineering Machinery,2019). Intelligent and unmanned emergency rescue equipment has become an integral part of modern disaster rescue.
At present, there is a lack of research in the testing and evaluation of intelligent and unmanned emergency rescue equipment, which can provide a basis for further improvement. The focus of research of testing and evaluation of equipment used in disasters is not only the equipment itself, but also the analysis of the environment to obtain its requirements for equipment. By analyzing the characteristics of typical geologic disasters, this paper builds a testing and evaluation index system for intelligent and unmanned emergency rescue equipment based on the requirements for equipment in the emergency rescue of large geological disasters such as earthquake, debris flow, barrier lake and other disasters caused by them, which provided a basis for the subsequent research of testing and evaluation of equipment.

2. Analysis on Characteristics of Typical Geological Disasters

Geological disasters, referred to Regulations on the Prevention of Geological Disasters, are those related to geological action caused by natural factors or human activities that endanger the life and property security of people, such as collapse, landslides, and debris flows (The

Central People's Government of the People's Republic of China, 2005). Generalized geological disasters refer to the phenomena and events that produce sudden or progressive damage to the geological environment due to geological action and cause the loss for human. It not only includes endogenous geological disasters such as earthquake and volcanic eruption, but also supergene geological disasters such as collapse, landslide, and debris flow. This paper mainly focuses on typical geological disasters, such as earthquake, collapse, landslide, debris flow, and barrier lake, which are caused by natural factors.

2.1 Disaster Chain

A series of secondary disasters are often induced at a certain time or region after some disasters. Several disasters in the disaster chain are interacting and destructive. Disaster chains are especially common in geological disasters, especially those caused by earthquakes. In addition to aftershocks, earthquakes are also prone to collapsing, landslides and debris flows, as well as continuing to cause barrier lakes. For example, when the landslide enters the river valley, landslide dams and landslide barrier lakes will be formed by large-scale landslide, while medium and small-scale ones will become the material source of debris flow. In extreme cases, debris flows can also block up rivers and result in barrier lakes. There are over 400 recorded barrier lakes in China, of which 256 were triggered by the 2008 Wenchuan Earthquake.

2.2 Frequency

Mountains, plateaus, and hills in China account for about two-thirds of the total land area. The terrain is high in the west and low in the east with a stepped distribution and it decreases sharply at the boundary, which is a prone area of geological disasters such as collapse, landslides, and debris flows. In addition, China is in the two most active seismic belt in the world, with the circum-Pacific seismic belt in the east and the Alps-Himalayas seismic belt in the west and southwest. Affected by topographic landform, stratum lithology, slope structure and geomorphic evolution, China has a wide range of sudden geological disasters, which is one of the countries with the most serious geological disasters in the world. The frequency of other geological disasters is also affected by the occurrence of large-scale geological disaster. After the Wenchuan Earthquake, the overall frequency of geological disasters such as debris flow, collapse and landslide in Longmen Mountain area has increased significantly, which is about 4.8 times higher than that before the earthquake.

2.3 Serious Damage

Typical geological disasters generally have tremendous destructiveness. If disasters occur in densely populated or economically developed areas, they will cause many casualties and huge economic losses. Next, disaster chain leads to large-scale geological disasters inevitably deriving other disasters, with a long duration and serious indirect damage. For example, aftershocks tend to last for a long time. As of July 2009, 58,401 aftershocks caused by the 2008 Wenchuan Earthquake were recorded. The Wenchuan Earthquake also triggered tens of thousands of landslides and formed various disaster chains, such as Tangjiashan barrier lake. All of these have caused enormous damage to live and property of people, making it difficult to complete the rescue, recovery and reconstruction work in the disaster in a short period of time, and also bringing great negative impact to rescuers and people in the disaster.

2.4 Emergency, Difficult and Dangerous Rescue

First, rescue time is urgent. Golden rescue times exist for all kinds of disasters. The survival rate of survivors will decrease with time in the face of the stress of air, temperature difference, and energy, and may lose life at any time under prolonged physiological and psychological distress. Second, rescue assignments are difficult. In emergency rescue, there are often problems such as difficult detection of disaster conditions and difficult passage of roads. It is difficult for large rescue machinery to be delivered to site in the early stage of rescue, which causes low efficiency of disposal. Third, rescue environment is dangerous. Typical geological disasters mostly occur in complex environments, bad weather and hidden dangers of secondary disasters, which directly threaten the safety of rescuers and the people affected.

3. Demand analysis of emergency rescue equipment

Emergency rescue equipment is the combat weapon, which is used to improve emergency rescue capability and efficiency. Once disasters occur, people can only actively rescue and relieve them, minimizing various losses. Because the emergency rescue equipment has various classification and different functions, based on the characteristics of typical geological disaster, this paper analyses the function requirements of emergency rescue equipment corresponding to emergency rescue, and highlights the intelligent and unmanned demand of equipment.

3.1 Disaster Detection

Geologic and geomorphic environment will be changed after a disaster. There are also other factors such as harsh meteorological conditions, unstable damaged buildings, blocked public communication networks, and the risk of secondary disasters at any time. Such a dangerous rescue environment prevents rescuers from blindly entering the disaster site. Detection equipment is needed to collect field information, which is used to help rescuers quickly and accurately grasp the situation on the spot, formulate rescue plans, optimize equipment configuration plans, and construct safety monitoring of operating environment, to ensure the scientific, efficient, and safe rescue.

There are still difficulties in collecting information at the disaster. Observation satellites focus on the overall situation of disasters, but it is difficult to provide accurate field conditions due to meteorological conditions, mountain, gorge. Search and rescue robots focus on single information such as terrain and life characteristics in acquisition and transmission, so it is difficult to obtain multi-source information of disaster. Generally, remote control technology is used in robots, so it cannot intelligently judge and select search and rescue operations according to complex environment and dynamic changes. Therefore, intelligence operation for comprehensive collection of environmental information is required for reconnaissance rescue robots, which can detect accurately in designated area by remote control operation, and autonomously in other areas. When autonomous detection is carried out, it also needs to drive independently at the rescue site. It provides effective on-site information for rescue work by detecting terrain, temperature, humidity, dust gas and other environmental information.

3.2 Main Operation

Engineering machinery has good versatility and applicability, which can be deployed in a large area with the functions of pushing, digging, assembling, dismantling, cutting and other operations. It is the main combat equipment in emergency rescue, which participates in road access, debris clearance, demolition and removal, public facilities repair, and other tasks. There are two main types of demand for engineering machinery in emergency rescue, lifeline opening and disaster site operation. Opening the life passage is the precondition for emergency rescue and treatment of the injured. Traffic and buildings in and around the disaster will be damaged to varying degrees, which will make it difficult for rescue equipment to enter and transport the victims. The purpose of lifeline is to deal with the traffic infrastructures such as roads, bridges, tunnels damaged by disasters, and to provide access for rescue equipment, rescuers, materials, and disaster victims. Disaster site operation aims at saving lives, and its main task is to remove the obstacles that affect the safety of life in the disaster. The specific operations required for different disaster sites will differ. Here are examples of ruins clearance after earthquake and disposal of barrier lake. After the earthquake, the site needs equipment to clean up the ruins, break the concrete and build the lifting to create conditions for rescuing the buried people. In disposal of the barrier lake, the equipment needs to open the discharge channel through excavation, pushing and drilling and blasting to realize the control discharge.

However, the emergency and danger of rescue also put forward new requirements for the intelligence and unmanned construction machinery. The biggest difference between lifeline opening and disaster site operation and general engineering work is the degree of emergency. Continuous operation with main warfare equipment is required in most rescue operations, with dozens of operators changing shifts without changing equipment. But long-term continuous work will cause stress to the rescuers both physically and mentally. In addition, some areas are inaccessible to rescuers due to environmental pollution, obstacles, potential secondary disasters. Remote control operation becomes the direction of intelligent and unmanned construction machinery rescue equipment. Through remote control operation, equipment can realize real-time monitoring and operation in dangerous scenes, self-operation for high-frequency repetitive actions in the process of rescue to improve efficiency under the premise of ensuring the life and safety of rescuers.

3.3 Assistant Operation

Main rescue equipment is generally large engineering machinery, which has heavy quality, high requirements for road transport conditions, and is not easy to transport quickly in the early stage of disasters. Assistive rescue equipment is an effective complement to large engineering machinery, which can replace manual work in risk environment to carry out auxiliary operations such as handling and excavation in the early stage of disasters. However, it has very limited flexibility, loading capacity, and intelligence. Similar to reconnaissance equipment, assistive equipment can carry out remote handling, excavation, fire extinguishing and other auxiliary rescue tasks at the rescue by remote control and autonomous driving. This type of equipment is used for emergency rescue in the early stages of disasters and can provide support for other rescue equipment entering the scene, improving the efficiency of rescue while ensuring the safety of rescuers.

3.4 Transport and Delivery

Road damage, bridge collapse, and culvert damage often occur around afflicted area, which lead to the failure of emergency rescue equipment and materials to reach the rescue site in time. Transport and delivery equipment refers to vehicles and other means of transportation used to transport rescuers, rescue equipment and materials during disaster rescue. It is difficult to meet the demand for equipment delivery because of the small number of helicopter units, base locations, and the difficulty in deployment in the existing emergency rescue system in China. Transport and delivery equipment with high trafficability in complex environment has the problem of low driving speed on damaged pavement after disaster, and some sections have potential secondary disasters, which can easily threaten the lives and safety of rescuers. With remote-controlled intelligent driving and local regional autonomous driving, transport and delivery equipment can walk through an unstructured dangerous road quickly and safely. Through precise control of the end track of the arm, the equipment can realize the precise remote-control loading and unloading operation of large load, implementing unmanned loading and unloading of equipment and materials.

3.5 Positioning and communication

At the site of geological disaster, there are problems such as location failure and communication discontinuity caused by blocked satellite signals and damaged communication base stations. The command and scheduling of the rescue forces can be seriously affected if there is no quick and accurate exchange of orders between the rescue team and the command department. Traditional networks cannot meet the application requirements in such complex areas as network coverage and stability. At present, there is a lack of technology of high accuracy, reliable positioning, and remote networking communication of rescue equipment in extreme environment. Meanwhile, the location accuracy and stability are challenged by the harsh and changeable disaster.

3.6 Overall Demand

Emergency rescue sites with urgent time, difficult operation and dangerous environment all put forward the demand for intelligent and unmanned rescue equipment, which is to realize autonomous driving on dangerous roads and intelligent operation in dangerous areas. Autonomous driving means that equipment can independently identify obstacles affecting driving and carry out corresponding actions of obstacle avoidance, obstacle crossing and hill climbing according to the characteristics of obstacles to ensure the passage of equipment. Intelligent operation mainly refers to security monitoring and remote-control operation, which obtains the security status of equipment in real time through security monitoring and prevents rescuer from entering extremely dangerous field by remote control. These can reduce the pressure of rescuers, ensuring that rescue teams carry out life rescue scientifically, efficiently, and safely.

4. Construction of Intelligent and Unmanned of Testing ang Evaluation Index System for Emergency Rescue Equipment

Intelligent and unmanned emergency rescue equipment has become one of the development directions to improve the efficiency of emergency rescue. However, the related testing and evaluation of it lack corresponding research, which cannot evaluate the performance of the equipment. Establishing a scientific and reasonable testing and evaluation index system for intelligent and unmanned emergency rescue equipment is helpful to fill the gaps in equipment performance evaluation and improve the quality of emergency rescue equipment. Therefore, based on the analysis of intelligent and unmanned demand for equipment in emergency rescue scenarios of typical geological disasters and according to the principle of building testing and evaluation index system, an index system for emergency rescue equipment is built.

4.1 Principles

The construction of testing and evaluation index system follows the principles of safety, feasibility, systematicness and scientificalness, considering the intelligent and unmanned demand of emergency equipment corresponding to typical geological disasters comprehensively. The selection of indicators basically follows the measurable principle, which should better reflect the impact and constraints of intelligent unmanned performance and function of equipment.

4.2 Construction of Testing and Evaluation Index System

According to the specific analysis of intelligent and unmanned demand of emergency rescue equipment, specific indexes are put forward from two aspects of intelligent operation and autonomous driving. Due to the large number of indicators and the common characteristics of some indicators, specific indicators should be clustered and grouped in different levels. The index system of intelligent and unmanned emergency rescue equipment includes four layers of evaluation target, performance index, specific function, and index parameter. The first layer is the target layer which is intelligent and unmanned emergency rescue equipment. The second layer is the criteria layer, including autonomous driving and intelligent operation. The third layer is feature layer, containing specific functions of the performance to be evaluated. The fourth layer is index layer, which is the specific index of the evaluation object. The index system of intelligent and unmanned emergency rescue equipment is shown in Table 1.
Specific functions of autonomous driving include intelligent obstacle crossing, intelligent obstacle avoidance and autonomous hill climbing. Through perception, decision-making and execution, equipment can autonomously cross vertical and horizontal obstacles, avoid obstacles that cannot be crossed through path planning, and adjust driving force by self-perception when climbing. Specific indexes of intelligent obstacle crossing include effective perception distance of vertical obstacle, maximum crossing height of vertical obstacle, effective perception distance of horizontal obstacle and maximum crossing width of horizontal obstacle. Specific indexes of intelligent obstacle avoidance include effective perception distance of positive obstacle, effective perception distance of negative obstacle and path planning ability. Specific indexes of autonomous hill climbing include maximum climbing slope and yaw angle.
Specific functions of intelligent operation include security monitoring and remote-controlled operation. The equipment is equipped to carry out alarms when an abnormal condition occurs by monitoring security information and operates the equipment by remote control. Specific indexes of security monitoring include safety information quantity, security warning time delay, abnormal security information detection rate and accuracy rate. Specific indexes of remote-controlled operation include remote-controlled operation scope, time delay, precision, and picture return time delay.

Table 1 - Testing and evaluation index system of intelligent and unmanned emergency rescue equipment

Target layer	Criteria layer	Feature layer	Index layer
Intelligent and unmanned emergency rescue equipment	Autonomous driving	Intelligent obstacle crossing	effective perception distance of vertical obstacle
			maximum crossing height of vertical obstacle
			effective perception distance of horizontal obstacle
			maximum crossing width of horizontal obstacle
		Intelligent obstacle avoidance	effective perception distance of positive obstacle
			effective perception distance of negative obstacle
			path planning ability
		Autonomous hill	maximum climbing slope

		climbing	maximum climbing yaw angle
	Intelligent operation	Security monitoring	quantity of safety information
			security warning time delay
			abnormal security information detection rate
			abnormal security information accuracy rate
		Remote-controlled operation	remote-controlled operation scope
			remote-controlled operation time delay
			remote-controlled operation precision
			picture return time delay

5. Conclusion

This paper analyzed the characteristics of typical geological disasters, such as chain-occurring, frequency, serious damage and emergency rescue. According to disaster characteristics, the requirements of typical geological disaster emergency rescue scenarios for equipment was extracted, including disaster detection, main operation, assistant operation, transport and delivery, positioning and communication. Then, the function and performance requirements of intelligent and unmanned equipment was further analyzed. Next, based on the specific analysis of intelligent and unmanned demand of emergency rescue equipment, specific indexes were put forward from two aspects of autonomous driving and intelligent operation, and the corresponding testing and evaluation index system of emergency rescue equipment was constructed. The index system represents the core functions and performance of intelligent and unmanned equipment objectively and scientifically, which can provide a basis for subsequent research of testing and evaluation.
Building testing and evaluation index system of intelligent unmanned function and performance for the specific functions and use scenarios of each type of emergency rescue equipment need to be studied in the following research. Then the test method and specific index parameters need to be researched.

6. Acknowledgement

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