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Application of Drone Remote Sensing in Emergency Response and Prevention of Geologic Hazards

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Abstract: This article aims to discuss the application of unmanned aerial vehicle (UAV) remote sensing in emergency response and prevention of geological disasters in China. Disasters are characterized by suddenness and unpredictability, which pose significant challenges to emergency rescue efforts. China is one of the countries in the world that experiences the most frequent and severe geological disasters, with features such as wide distribution, strong suddenness, and severe losses. Due to its rapid response, high efficiency, and low cost, UAVs have become powerful tools for emergency rescue in geological disasters. This article first introduces the application background of UAV remote sensing in the field of geological disasters, and then presents the application history of UAV remote sensing. Ultimately, the research concludes that since the 21st century, especially in the past decade, UAV remote sensing technology has developed rapidly, and with its rapid commercialization and popularization, the application of UAVs in various industries has shown a rapid growth trend. Currently, the application of UAV remote sensing in China's geological disaster industry mainly focuses on emergency investigation and disaster assessment, geological disaster investigation and evaluation, and dynamic monitoring of geological disasters. However, the main purpose and core value of applying UAV remote sensing in geological disaster prevention and control still only lie in obtaining basic information such as digital orthophoto images and digital terrain, and there is relatively little involvement in industry-level data mining, multi-source information fusion, and comprehensive model establishment, which are crucial for disaster prevention and mitigation and early warning.

Keywords: Drones; remote sensing; geologic hazards; emergency response and prevention.

1. Background on the Application of Drone Remote Sensing in The Field of Geohazards

As one of the regions with frequent geological disasters in the world, China's disasters are characterized by wide spatial distribution, sudden occurrence and serious consequences[1]. The complex topography and geomorphology result in a scattered distribution pattern of potential disaster sites[2]. According to the statistics from the "National Geological Disaster Bulletin", a total of 39,328 geological disaster events were recorded across the country from 2014 to 2018, causing a cumulative total of 1,558 casualties and economic losses of 1.63 billion yuan. It is worth noting that against the backdrop of global climate change, extreme meteorological events occur frequently, coupled with the intensification of seismic activities, which has kept the risk of geological disasters in China at a persistently high level. The survey results of the Ministry of Natural Resources in 2020 show that 330,000 geological disaster hazard points have been identified across the country. However, there are still many potential hazards that have not been identified, which indicates that the geological disaster investigation work still faces major challenges[3].

According to the geological disaster monitoring data of the Ministry of Natural Resources (2020- March 2022), a total of 12,816 geological disaster events were recorded across the country. Statistics by disaster type show that: Landslide disasters accounted for the highest proportion (7,187 cases, 56.1%), followed by collapses (3,672 cases, 28.6%), debris flows (1,274 cases, 9.9%), ground subsidence (500 cases, 3.9%), ground fissured (164 cases, 1.3%), and ground settlement (19 cases, 0.1%). Disaster level analysis indicates (2021- March 2022) : There were 36 extremely large-scale disasters (0.7%), 28 large-scale ones (0.6%), 329 medium-sized ones (6.6%), and 4,583 small-scale ones (92.1%). The cumulative number of casualties reached 297 (232 deaths/disappearances and 65 injuries), and the direct economic loss reached 8.26 billion yuan. It is worth noting that during the same period, 1,444 disasters were successfully predicted through the early warning system, effectively protecting the lives of 43,890 people and avoiding economic losses of 2.45 billion yuan, highlighting the significant disaster reduction benefits of the monitoring and early warning system.

The improvement of the early identification and early warning capabilities of geological disaster hazards is of crucial significance for disaster prevention. This requires the establishment of a collaborative prevention and control system of "human defense + technological defense". Remote sensing technology has become a core technical tool for the prevention and control of geological disasters by virtue of its macro-observation capability, multi-scale analysis characteristics and multi-dimensional monitoring advantages (visible light, thermal infrared and microwave multi-spectral synergy). China has established the “National Synergistic Mechanism for Unmanned Aircraft Emergency Response to Major Natural Disasters”[5]. Practice has shown that, in the emergency response to major disasters in recent years (e.g., the Jiuzhaigou earthquake, the Baige landslide, etc.), the UAV remote sensing system has demonstrated its technological advantages of all-weather response, high-precision modeling and real-time monitoring, thus realizing the construction of an integrated three-dimensional monitoring network of “air-sky-earth” at the site of the disaster.

2. History of the Application of Remote Sensing from Drones

UAV (Unmanned Aerial Vehicle) is an UAV that realizes autonomous flight through radio remote control or on-board computer programs, and mainly consists of a power system, a navigation module and a mission payload. Since its synchronous development with manned aircraft in the early 20th century, UAV technology has formed a complete spectrum. According to statistics, more than 50 countries around the world have deployed more than 300 types of UAV systems, typical representatives include the U.S. "Global Hawk" strategic reconnaissance UAV, China's "ASN" series of high-altitude and long-endurance UAVs, Britain's "Phoenix" series of UAVs, and the U.K. "Phoenix" series of UAVs, which are mainly composed of power systems, navigation modules and mission payloads. Typical representatives include the U.S. "Global Hawk" strategic reconnaissance UAV, China's "ASN" series of medium-altitude, high-altitude and long-endurance UAVs, the UK's "Phoenix" tactical UAVs, and Israel's "Skylark" micro UAVs.

UAV remote sensing system is a comprehensive measurement platform that uses fixed-wing, rotary-wing or vertical take-off and landing UAVs as carriers and integrates optical/infrared/laser sensors to implement high-resolution aerial remote sensing in low airspace [6]. The system can generate eight types of basic geographic information products: ①720° panoramic image; ②3D point cloud; ③digital surface model; ④digital orthophoto; ⑤3D grid model; ⑥3D visualization video; ⑦digital elevation model; ⑧digital line drawing. Application analysis shows that digital orthophotos are most widely used in landslide identification and building damage assessment, followed by digital elevation models, which are mainly used for terrain analysis and flood simulation. Three-dimensional data products (point clouds and grids) are less used in slope stability analysis and three-dimensional reconstruction of disaster bodies, while raw video data are mainly used in emergency search and rescue.

The basic results of UAV remote sensing are in the following eight categories: 720° panorama, 3D point cloud, digital surface model, digital orthophoto, 3D model, 3D scene flight video, digital elevation model, and line-delineated contour topographic map. The most popular of these is the orthophoto, which typically provides observations of mass movement, slopes susceptible to mass movement, building damage, surface features of fault zones, and land cover in flood zones.The DEM is the second most commonly used data type, and is most commonly used for mass movement, faulting, flooding, and topographic mapping of coastal areas. Raw imagery is a close second and is commonly used for observations of mass movement, building damage, and humans. Three-dimensional data types (i.e., point clouds and grids) are both used less frequently and are most commonly used for reconstructing mass movements, slopes susceptible to mass movements, and damaged buildings. Raw video was rarely used and was most often used to observe humans.

UAVs were initially used in 2000 and eventually used for civil remote sensing at the beginning of this century, and their popularity has been increasing year by year[7]. Into the 21st century, especially since the past decade, UAV remote sensing technology has developed rapidly, coupled with rapid commercialization and civilization, the application of UAVs in various industries has shown rapid growth.

From the technical evolution history, the development of UAV remote sensing in China can be divided into three stages.

(1) Military-led period (1980-2007): mainly serving in the field of national defense, with only sporadic research in the civil field, and technical research and development focusing on the improvement of the flight control system and the miniaturization of the payload.

(2) Civil Exploration Period (2008-2012): With the breakthrough of multi-rotor technology, the penetration rate of civil market increased significantly. The field of geologic disasters began to apply UAVs to identify hidden dangers, but the core technology patents are still in a blank state.

(3) Outbreak of growth (2013-present): Benefiting from the popularization of consumer-grade drones and the miniaturization of sensors, the industry application has shown exponential growth. A complete technology chain has been formed in the field of geologic disaster prevention and control, from hidden danger identification, emergency investigation to monitoring and early warning, and the number of related patents and articles have shown an explosive growth trend.

3. Current Status of UAV Remote Sensing Applications in The Field of Geohazards

China's large-scale application of drones in emergency response to major natural disasters began with the Wenchuan earthquake that occurred on May 12, 2008 in Sichuan Province[8]. At that time, the State Bureau of Surveying, Mapping and Geographic Information, the National Disaster Reduction Center of the Ministry of Civil Affairs (Satellite Disaster Reduction Application Center of the Ministry of Civil Affairs), the Chinese Academy of Sciences, Wuhan University, the University of Electronic Science and Technology, the Southwest Jiaotong University and other units have gone to the disaster area to use unmanned remote sensing technology to obtain and process airborne remote sensing imagery and to carry out assessment and analysis of the earthquake and secondary disasters, which provides important basic information for the scientific decision-making of disaster reduction and relief, as well as for the emergency command. On July 31, 2009, a seminar on the cooperation mechanism of unmanned aircraft for emergency monitoring of major natural disasters was held in Beijing; on January 29, 2010, the National Disaster Reduction Center of the Ministry of Civil Affairs (Satellite Disaster Reduction Application Center of the Ministry of Civil Affairs) organized and held the "Signing of the Cooperation Agreement on Unmanned Aircraft Monitoring Stations for Emergency Response to Major Natural Disasters of the State" and the awarding of licenses in Beijing. On January 29, 2012, the National Disaster Reduction Center of the Ministry of Civil Affairs (the Satellite Disaster Reduction Application Center of the Ministry of Civil Affairs) organized and held the "Signing of Cooperation Agreement and Awarding Ceremony of National Major Natural Disaster Emergency Drone Monitoring Stations" in Beijing, in which the first batch of seven units signed a contract with the National Disaster Reduction Center and were awarded the title of "National Major Natural Disaster Emergency Drone Monitoring Stations". In 2012, a nationwide remote sensing disaster emergency monitoring network was initially formed, marking the gradual emergence of UAV remote sensing monitoring as an important part of China's three-dimensional monitoring system for natural disasters, and the application of UAV remote sensing monitoring system in the field of disaster mitigation and relief in China has stepped up a new level. Since then, UAV remote sensing monitoring system has been used in major earthquake disasters (e.g., 2010 Yushu earthquake in Qinghai, 2011 Yingjiang earthquake in Yunnan, 2014 Ludian earthquake in Yunnan, 2017 Jiuzhaigou earthquake, etc.), and in major geological disasters (e.g., August 7, 2010 Zhouqu mega mudslide in Gansu, December 10, 2015 landslide in Guangming New District in Shenzhen, September 28, 2016 Lishui landslide in Zhejiang, and June 24, 2017 landslide in Zhejiang, etc.). landslide, June 24, 2017 Maoxian landslide in Sichuan, August 28, 2017 Bijie landslide in Guizhou, October 11, 2018 Jinsha River landslide, March 15, 2019 Linfen landslide in Shanxi, July 23, 2019 ShuiCheng landslide in Guizhou, etc.) emergency rescue in the remote sensing of drones has become support.

Many papers have outlined UAV-based pre- and post-disaster remote sensing applications[9-10]. These review articles provide in-depth explanations of specific hazard applications related to: landslides and other large-scale movements (risk assessment and modeling, detection, monitoring, and impact assessment); floods (risk assessment and modeling, inspection of protective structures, and impact assessment); earthquakes (fault zone mapping, impact assessment, and reconstruction monitoring); volcanoes (topographic, thermal, and lava flow monitoring); and wildfires (monitoring)

After more than ten years of development, the current UAV remote sensing applications in China's geohazard industry are mainly focused on three aspects: emergency investigation and disaster assessment, geohazard investigation and evaluation, and dynamic monitoring of geohazards.

3.1. Emergency Investigation and Disaster Assessment

UAV remote sensing has become a core technical means for emergency response to geological disasters. Its characteristics of mobility, flexibility and rapid deployment (low requirements for take-off and landing sites) effectively solve the problem of delayed information acquisition caused by traffic interruption in traditional means[6,11], providing key support for disaster situation assessment and rescue decision-making. After years of practical application, a standardized process covering flight planning, rapid image processing, disaster interpretation and loss assessment has been formed[11–14].

Even so, some obvious changes have occurred in the emergency investigation and disaster assessment of geological disasters by drones, which can be divided into the following three aspects: Firstly, in terms of application objects, it has gradually expanded from the early major earthquake disaster emergency response led by the state and the secondary geological disasters it triggered, which were numerous and widespread, to the emergency response for major single geological disasters led by the state, provinces and cities. In recent years, there has been a trend to further expand to the emergency response for a large number of medium and small-scale geological disasters (risks) led by cities, counties and even towns. Then, In terms of the implementing entities, it has gradually expanded from the early national-level professional units related to UAVs and remote sensing to provincial and municipal-level professional geological exploration and other technical units as well as UAVs and remote sensing related enterprises. In recent years, there has been a trend of further expansion to the geological disaster prevention and control administrative departments and local professional technical units at the municipal, county and even township levels. Finally, in terms of the UAV remote sensing equipment adopted, it has gradually expanded from the early complex and specialized large and medium-sized fixed-wing UAV systems that were equipped with aerial measurement cameras and had strict requirements for take-off and landing sites to vertical take-off and landing fixed-wing and multi-rotor UAV systems that are equipped with high-performance single-lens reflex cameras and have significantly reduced requirements for take-off and landing sites. In recent years, small drones equipped with ordinary digital cameras, even consumer-grade drones and "pocket phones", have begun to be widely used, and there are no special requirements for take-off and landing sites. It is not difficult to see that these changes are a concrete reflection of the civilian application boom brought about by the rapid development and maturity of small UAV remote sensing technology.

3.2. Geological Hazard Investigation and Evaluation

With the gradual popularization of small UAV remote sensing technology, it has been adopted in a large number of routine geological disaster investigation and evaluation. For example, in addition to the application in typical landslide areas, typical mudslide areas, and typical high-level collapse landslide areas[15], UAV remote sensing is also widely used in the investigation and evaluation of geologic hazards in pipeline projects [16] , transportation arteries, tourist areas[17] , plateau mining areas, mining areas, abandoned mines, towns and cities, loess areas[16], and so on.

In this application, the system composition of UAV remote sensing, field operation, results processing and other technical methods and processes are basically the same as the emergency investigation. However, the maps used for investigation and evaluation generally pay more attention to the fineness, so more attention is paid to the camera calibration of the UAV remote sensing system, the acquisition of high-precision attitude and positioning system data, and the deployment and measurement of ground image control points. In addition, this work tends to be combined with other spatial information technologies such as geographic information systems (GIS) and laser radar (Light Detection and Ranging). The focus is placed on high-precision remote sensing information to obtain geohazard image interpretation (including the selection of interpretation methods and the establishment of interpretation markers[16,18,19], information extraction, evaluation model construction[20] quantitative analysis and precise description, and even the analysis of typical geohazard characteristics and causal mechanisms. In short, through the UAV remote sensing method can be relatively low-cost to obtain the present situation of good, high resolution, high precision digital orthophoto and digital terrain and other forced sensing results, so as to provide important basic information for the investigation and evaluation of geologic hazards.

3.3. Dynamic Monitoring of Geological Hazards

The application of UAV remote sensing technology in the field of geological disaster prevention and control mainly presents phased characteristics. In application scenarios such as emergency investigation and disaster assessment, as well as routine investigation and evaluation, this technology mainly functions as a single identification and lacks the ability for continuous monitoring. However, the continuous monitoring of identified geological disaster bodies has significant scientific value. By obtaining the dynamic evolution data of disaster bodies, it can provide a key basis for the study of disaster mechanisms and the construction of early warning and prediction models. This demand also explains the necessity of China's geological disaster prevention and control system's long-term emphasis on technical routes such as "mass monitoring and prevention", "specialized monitoring", and "combination of mass and specialized monitoring".

At present, the application of UAV remote sensing in repetitive monitoring has obvious type selectivity. Typical case studies show that this technology is mainly applied to the monitoring of debris flow disasters. For example, the Sichuan Provincial Institute of Geological Survey conducted a monitoring study on the debris flow in Zoumalinggou, Mianzhu after the Wenchuan earthquake. By integrating multi-source data such as aerial images, satellite images and UAV images, the formation conditions and three-year evolution characteristics of the disaster were systematically analyzed. In addition, in the field of mine environmental monitoring, dynamic monitoring practices combining multi-phase satellite and UAV images have also emerged.

Technical limitations are the main factors restricting the promotion and application of UAV remote sensing in the dynamic monitoring of geological disasters. The primary limitation lies in the measurement accuracy. The positioning accuracy of the current UAV system has not yet reached the centimeter-level or even millimeter-level standards of the Global Navigation Satellite System (GNSS), making it difficult to meet the precise monitoring requirements of creep geological disasters such as landslides. Secondly, vegetation coverage significantly affects data quality. The optical sensors carried by conventional UAVs cannot penetrate vegetation to obtain true surface information. Even the high-cost LiDAR technology has obvious limitations in areas with dense vegetation.

Although the application of UAV remote sensing technology in the prevention and control of geological disasters in China started relatively late, it has developed rapidly. Especially in the field of major disaster emergency response, through the collaborative working mechanism established at the national level, this technology has rapidly grown into a fundamental supporting means for disaster emergency investigation. The application scope has gradually expanded from the initial emergency response to multiple links such as regular investigation and evaluation and dynamic monitoring, and is increasingly becoming an important component of the geological disaster prevention and control technology system.

However, in-depth analysis shows that there are still several prominent problems in the current application: Firstly, in terms of the coverage of the technical system, UAV remote sensing mainly focuses on emergency prevention and control (85% application maturity) and investigation and evaluation (65%), and is still in the pilot stage in monitoring and early warning (20%), while there is a lack of typical cases in the field of comprehensive governance. Secondly, in terms of the depth of technology application, over 80% of the applications still remain at the level of basic data acquisition, the multi-source data fusion rate is less than 15%, and the proportion of deep applications such as predictive model construction is less than 5%. Finally, at the level of technology promotion, the actual application rate of grassroots prevention and control units such as districts, counties and towns is relatively low. The use of equipment mostly remains at the stage of simple image collection, lacking systematic data processing and analysis capabilities. This situation is significantly different from the actual needs of geological disaster prevention and control in our country. According to statistics, small and medium-sized geological disasters account for over 98% of the total, causing direct economic losses of more than 50%, and the prevention and control of these disasters mainly rely on grassroots technical forces. Although government departments at all levels have increased the allocation of equipment in recent years, due to insufficient technical training and an imperfect maintenance system, the actual usage efficiency of the equipment has not been fully exerted.

4. Results and Discussion

The results of this paper show that since the 21st century, especially in the past decade (2010-2020), UAV remote sensing technology has undergone remarkable innovative development and technological breakthroughs. With the rapid commercialization process of this technology and its extensive penetration in the civilian field, its application in various industries has shown an exponential growth trend. In the field of geological disaster prevention and control, the application of UAV remote sensing technology mainly focuses on the following three key directions: (1) Disaster emergency investigation and rapid assessment of disaster conditions; (2) Systematic investigation and comprehensive evaluation of geological disasters; (3) Dynamic monitoring and early warning of geological disasters.

However, an in-depth analysis of the current application status reveals that the main function of UAV remote sensing in geological disaster prevention and control is still limited to the acquisition of basic geographic information, specifically manifested in the production of basic data such as digital orthonormal images (DOM) and digital terrain models (DTM). In contrast, in the core demand areas of disaster prevention and control - including key technical links such as multi-source heterogeneous data fusion analysis, disaster prediction model construction, and risk assessment system establishment - the in-depth application of UAV remote sensing technology is still insufficient. The limitation of the application depth of this technology directly affects its potential value in enhancing the efficiency of disaster prevention and mitigation and improving the accuracy of disaster early warning.

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