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In-depth Thinking on the Practical Application Mode of Multi-Rotor UAVs in the Firefighting Rescue

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Abstract: *With the continuous development of social economy and firefighting rescue technology, multi-rotor unmanned aerial vehicles (UAVs) have become an indispensable part of firefighting rescue. Faced with the occurrence of various types of disasters, there is a higher demand for the application of multi-rotor UAVs in firefighting rescue. They can improve the work efficiency of pre-scanning, assisting rescue decision-making, loudspeaker illumination, daily inspections, and special environment operations for firefighting rescue teams. Based on the current deployment of UAVs in the Jiaxing Firefighting Rescue Brigade and a comprehensive large-scale practical exercise, the author summarizes the common applications of multi-rotor UAVs in the field of firefighting, analyzes the problems encountered in the practical application of firefighting and rescue operations, and provides suggestions for improvement and optimization to enhance the efficiency of multi-rotor UAVs in firefighting rescue.*

Keywords: *multi-rotor UAVs; firefighting rescue; practical application*

1. Introduction

Since the reform and transfer of the firefighting rescue force, the mission positioning of “being capable of dealing with all disaster types, and being able to handle major emergencies” has become more complex and diversified, posing unprecedented challenges to firefighting and rescue work. However, as a historical product of technological, informational, and modern development, multi-rotor UAVs have the characteristics of ease of operation, precise positioning, and comprehensive perspective. They have played an irreplaceable role in firefighting and rescue, with an expanding application domain, providing favorable support for disaster reconnaissance and assisting decision-making and command for firefighting and rescue teams.

2. Background, purpose, and significance of multi-rotor UAVs research

The UAVs industry is a high-tech industry and strategic emerging industry encouraged by the state, and the industrial policies have strongly supported the development of the UAVs industry and created a favorable development environment. The Ministry of Industry and Information Technology and the Civil Aviation Administration of China and other government departments have issued the “Guiding Opinions on Promoting and Regulating the Development of Civil UAVs Manufacturing Industry,” which clearly defines the positioning of the UAVs industry as a national strategic high-tech industry. According to incomplete statistics, by 2022, the scale of China’s civilian UAVs market has reached 45.3 billion yuan, occupying an important share in the national consumer market.

Firefighting and rescue teams have carried out the development and exploration of multi-rotor UAVs based on the actual rescue work, forming multiple sets of tactics to support firefighting and rescue operations. The number of multi-rotor UAVs within the teams has developed rapidly like bamboo shoots after rain. The multi-rotor UAV described in this article is powered by three or more electric or fuel-driven devices. The number of rotating wings can be divided into four, six, eight, or even more, and the shape can be classified according to the spatial layout and the installation position of the rotating wings, such as “+”, “X”, “Y”, and “H” models. It plays an important role in providing remote command, secure and scientific rescue, and daily patrols for firefighting and rescue teams and performing operational tasks in special environments [1-2].

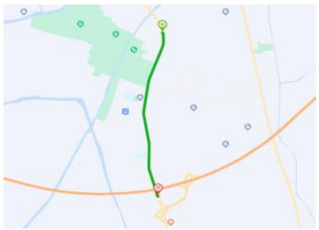
The development of multi-rotor UAVs is based on modern technologies such as mobile communication, telecommunications, the internet, big data, artificial intelligence, and remote control. This research aims to analyze the technology and methods of applying multi-rotor UAVs in firefighting and rescue operations, analyze the application effect, propose emergency response plans and contingency measures, evaluate the application effect of multi-rotor UAVs in firefighting practice, and lay the foundation for further improving emergency rescue capability and level.

3. Common applications of multi-rotor UAVs in the firefighting field

The author fully participated in the practical operation of urban complexes in Haining, Zhejiang in February 2023. According to the different environments in which multi-rotor UAVs are used, technical experts from mobile, telecommunications, and other departments were mobilized to use 5G technology to develop different application scenarios. This allowed for round-the-clock surveillance by UAVs, quick reconnaissance and detection of rescue missions, and accurate water firefighting capabilities. During this operation, various models such as DJI MRT300, M30T, Phantom 2, and Phantom 3 were used, along with fixed-wing and fixed-wing hybrid models. Cooperation and coordination between high-pressure vehicles, robots, fixed-wing UAVs, and hybrid UAVs were continuously deepened to improve the effectiveness of scene applications.

3.1. Round-the-Clock UAVs Surveillance at the Scene

Table 1: Comparison and Analysis of On-Duty Firefighting Vehicles and UAVs

Start/ end point	**Distance**	**The time used by UAVs**	**The time used by vehicles**	**weather**	**Temp.**	**Power at departure /return**	**Marking on the map**	**Situation of signal**
From the town fire rescue brigade to the south side of Huashi Clothing Co., Ltd.	3.7 KM	5 minutes and 3 seconds	9 minutes and 18 seconds	cloudy	23℃	88%/ 61%		The UAVs' signal is lost about 2 kilometers. Return to normal after 10 seconds.
From the town fire rescue brigade to the intersection of town. expressway and yaotai line	3.9 KM	5 minutes and 26 seconds	7 minutes and 27 seconds	cloudy	20℃	82%/ 54%		UAVs' signal is good, 3 to 4 grids.
From the town fire rescue brigade to the north of Ciyun Road.	3.6 KM	6 minutes and 1 seconds	10 minutes and 23 seconds	cloudy	20℃	91%/ 60%		UAVs' signal is good, 3 to 4 grids.
From the town fire rescue brigade to the front of the district public security. border checkpoint 200 meters.	2.4 KM	4 minutes and 2 seconds	6 minutes and 07 seconds	cloudy	25℃	76%/ 67%		After the UAV reaches the planned position, the signal is lost and it automatically returns.

The establishment of UAVs nests (Airfields) lays the foundation for safe UAVs control. They not only have functions like automatic storage, remote communication, data storage, and intelligent analysis but also possess complete mechanical systems. With these systems, UAVs can complete tasks safely, quickly, and accurately without human intervention, greatly improving operational efficiency. The implementation of round-the-clock surveillance for firefighting and rescue safety and control means that UAVs are dispatched to the rescue site in advance by sending latitude and longitude. According to field tests, when firefighting vehicles and UAVs receive the deployment order, the total distance traveled can be shortened by around 4 minutes under 4 km of normal urban road conditions, as shown in Table 1.

3.2. Rapid real-time deployment and information feedback for rescue missions

During the reconnaissance stage of practical operations, especially in large-scale, high-rise, and underground environments with significant fires, manual reconnaissance is dangerous and inefficient. It is difficult to comprehensively survey the entire fire scene to make the best judgments. Multi-rotor UAVs make full use of their advantages in flight altitude and precision. With their small size, low flight environment requirements, and flexible operation characteristics, they use devices such as infrared imaging cameras, video streams, and individual 4G or 5G image transmission to achieve real-time video feedback of disaster scene conditions. By utilizing UAVs aerial reconnaissance and hovering technology, the development trend of firefighting and rescue can be monitored in real-time to provide favorable reference for firefighting and rescue command decisions. Key information such as the ignition point, explosive materials, trapped personnel, and other important factors can be comprehensively assessed, improving rescue efficiency and accuracy, and laying the foundation and guarantee for fire investigations after the disaster. Considering the performance of the UAVs, the DJI M30T model was used as an example to conduct comprehensive extreme tests, as shown in Table 2.

Table 2: Multi-rotor UAVs flight performance test data for specific data.

Start/end of test	**Planning environment/field flight time**	**Time and power of takeoff**	**Flight altitude**	**Limit speed of flight**	**Return status of video**	**Time of arrival/return**	**Flight radius**	**Limit duration of battery life**	**Charging time of UAVs**
From the district fire rescue brigade to the district songniaidai port (east)	Plan an unobstructed route of 8 km; Estimated time is 23 minutes.	9: 56 /100%	120m	17m/s	Normal return, after 15 minutes of flight, the memory is full. (32G)	10:05 / 10:14	7.7km	Return automatically at 7.7km with 60% power.	It takes 27 minutes to charge from 10% to 90%, and 43 minutes to charge to 100%.
From the district fire rescue brigade to high-speed railway station (south)	The planned route is covered by high-rise buildings and is about 7 km; Estimated time is 22 minutes.	10:41/100%	115.7m	17m/s	Normal return	10:43 / 10:47	1.3km	Signal loss at 1.3km, and power consumption is 90% when returning automatically.	
From the district fire rescue brigade to the second people's hospital (west)	The planned route is 5.5km；; Estimated time is 18 minutes.	15:16/100%	120m	13m/s	Normal return, and real-time plotting is delayed for 1-2 minutes.	15:21 / 15:33	3.8km	Signal loss at 3.8km, and power consumption is80% when returning automatically.	
From the district fire rescue brigade to jiaxing 320 national road (north)	The planned route is 8 km; Estimated time is 24 minutes.	15:44/100%	120m	15m/s	Normal return	15:59 / 16:08	7.2km	Return automatically at 7.2km with 60% power.	

3.3. Continuous on-site illumination

During practical firefighting and rescue operations, the firefighting and rescue teams use handheld lights, headlamps, and portable lighting systems. However, these lighting devices have limitations in terms of irradiation range and brightness, which may not meet the requirements of practical operations. In this practical operation, a tethered UAVs power system was used to provide a reliable and continuous power supply for UAVs. The tethered UAVs have a wider coverage range and higher brightness. This addresses the pain points of short UAVs endurance and light payload capacity, allowing UAVs to carry heavier equipment and execute aerial tasks for longer periods of time. The video recording device on the gimbal is transmitted in real-time to the backend, providing a clear understanding of the situation on-site at any time. Through on-site field tests, it was found that the vertical illumination from the light source was clearer than other lighting devices, playing an irreplaceable role in night rescue operations[3-4].

3.4. Installing relay stations to enhance network efficiency

Compared with communication between ground fixed base stations, setting up an aerial base station has advantages such as reliable channels and flexible deployment. It is particularly suitable for providing temporary communication services as an aerial base station or relay assist for disaster-stricken areas or emergency situations. The UAVs relay platform is equipped with customized relay communication equipment, establishing an aerial communication bridge, which can effectively extend the communication distance and increase the wireless signal coverage radius. This provides more options for the application of small-scale wireless private networks in emergency scenarios. It is particularly applicable in certain special environments or emergency communications, such as chemical plant fires, underground tunnel fires, earthquakes, and rescue operations after water disasters. It can also provide multi-hop extension for existing wireless and wired networks, expanding network usage efficiency.

4. Challenges in the practical application of multi-rotor UAVs

Multi-rotor UAVs have played an important role in rescue organization command, on-site reconnaissance, firefighting and rescue operations, and fire suppression. At the same time, higher requirements have been put forward for the role and performance of UAVs. However, there are certain shortcomings in pilot proficiency, daily management, information data collection, and practical application.

4.1. Ineffective unified platform management

With the popularization of UAVs in rescue tasks, the generated data, relevant operators, and tasks are increasing, requiring unified platform storage and access. For the purpose of unified management of UAVs and their data, and to facilitate access, it is also considered to integrate various units' UAVs into a unified management platform to achieve unified airspace allocation and real-time supervision, ensuring the safety of aerial rescue forces and ground personnel facilities. There are few communications means in the rescue scenarios, and there are problems with smooth transmission of audiovisual information, "unreachable" and "invisible" issues. Currently, existing platforms mainly include UAVs control platforms, integrated air and ground control platforms, and DJI SSKY2 platforms. Major companies are competing to create their own management platforms, and simultaneously, the interoperability of platform data and unified scheduling have become current challenges[5].

4.2. Low proficiency in UAVs pilot skills

Strengthening research on UAVs combat, building professional teams of UAVs pilots, enhancing education and training on real-world applications, and accelerating the training of personnel for UAVs application and command capabilities are current issues that need to be addressed. Although at the level of general and regional headquarters, personnel are organized to obtain AOPA, UTC, and ASFC certifications each year, based on the analysis of the current practical applications, most UAVs pilots have relatively limited operational skills and knowledge. After grassroots team pilots obtain UAVs pilot certificates, due to concerns about potential accidents, such as fired machines, inadequate flight training time becomes a common issue leading to skill rustiness. Some units also lack supporting insurance coverage for machine damages, leading to a certain degree of reduced flight activity. In particular, training and research on flying in indoor and underground environments are lacking, as well as the study and consideration of UAV standard operation procedures.

4.3. Insufficient number of UAVs pilots for daily professional rescue missions

As a high-tech new equipment, UAVs require professional personnel to operate, maintain, and

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inspect. Currently, the size of the UAVs team is very limited, making it unable to respond timely to various fire rescue and maintenance needs. The number of UAVs pilots is also insufficient, with some grassroots stations having less than 2 personnel, who are mostly engaged in communication and alarm reception. This situation often leads to a shortage of available pilots, as well as inadequate personnel replacements and backup forces.

4.4. Battery and signal are greatly affected by environmental factors, limiting the usage scenarios of UAVs

Multi-rotor UAVs need to carry equipment such as thermal imaging cameras, voice communication systems, gas detectors, and fire extinguishing agents, which continuously reduce their endurance as the payload increases. Temperature also has a direct impact on UAVs' usage time. Based on testing, for every 1-degree Celsius decrease in temperature below 15 degrees, the battery's available capacity decreases by 0.8%, significantly reducing the usage time. Currently, the usage environment of UAVs is also limited, with flight operations being restricted by wind speeds above level 7, rain, enclosed tunnels, and indoor spaces. In fire environments, various factors such as dust, lighting, and temperature can interfere with signals and lead to errors during flight, which hinders efficient and accurate search and rescue operations.

5. Improvements and breakthrough suggestions for the practical application of multi-rotor UAVs

The future development of UAV technology will tend to be more diverse, informatized, and intelligent. Innovation in new technologies requires collaboration from multiple parties. It is necessary to enhance the capabilities of UAVs pilots of firefighting and rescue team, continuously explore, research, and test the application channels of UAVs in the rescue field, and explore comprehensive management platforms to achieve a "one-map" command and dispatch system, providing technical and logistical support for firefighting and rescue operations.

5.1. Training in UAVs operation skills

To improve the efficiency of UAVs applications in the fire field, emphasis should be placed on training UAVs operators. The training of UAVs pilots should be standardized and ongoing, increasing the number of UAVs pilots, establishing regular assessments for pilots training, and creating files for UAVs and pilots, tracking and guiding continuously and regularly for pilots retraining. In addition to basic knowledge, application technology, and maneuvering skills, training should include flight skills, aircraft modification, and emergency repairs. Flight simulation training software should be provided to enhance simulation training, allowing pilots to operate UAVs proficiently. Specialized training for obstacle crossing should also be conducted.

5.2. Professional testing of UAVs adaptability to different environments

Strengthen communication and cooperation with local UAVs management departments, professional institutions, and research and development teams to improve the efficiency of UAVs applications in the fire field. In the experimental and research stages, testing should focus on various emergency environments and special strategies, improving protective measures against environmental influences, enhancing flight safety and adaptability to the environment. Additionally, regular testing in special environmental conditions should be conducted to improve pilot adaptability and application in various scenarios.

5.3. Data integration and automation, establishing UAVs management platforms

In firefighting and rescue scenarios, UAVs can quickly respond and conduct reconnaissance, equipped with high-definition gimbaled cameras, gas detectors, laser mapping cameras, and other sensors to collect various types of data at the scenarios. This data is transmitted back to the command center through a UAVs cloud management system, providing a visual display of the situation. The "UAV + UAV cloud management system" model enables the scheduling of UAVs clusters, supporting centralized control and positioning of UAVs and UAVs nests, and facilitating synchronized collaborative operations between multiple automated UAV nests, combining human and unmanned resources. The platform supports marking targets, planning routes, and assigning work areas on the web, which automatically syncs to the UAVs nests and UAVs, enabling efficient coordination and real-time preview of on-site operations. Additionally, functionalities such as flight control, mission management, gas detection, pilots management, routine inspections, and intelligent alarm functions are integrated into the firefighting and rescue command platforms.

5.4. Improving the functionality of multi-rotor UAVs and special scenarios application

Firstly, utilization of UAVs with a payload capacity for long-range reconnaissance, material delivery, extended flight time, and strong load capacity can enable long-distance unmanned firefighting, reconnaissance, and material delivery operations after disasters. Secondly, utilizing UAVs capable of penetrating confined spaces for search and rescue missions to rapidly locate and rescue trapped individuals within disaster-stricken areas. Real-time monitoring and image recognition technologies can provide AI image recognition support to rescue personnel, facilitating precise rescue operations. Improving the use of UAVs in scenarios involving wind speeds above level 7 and temperatures below 15°C. Lastly, conducting fire inspections through two-dimensional and three-dimensional modeling of UAVs-controlled areas, establishing inspection routes, and using AI recognition capabilities of multi-rotor UAVs to identify blockages in fire escape routes based on the shape of vehicles or objects observed. The backend control platform can provide feedback and reminders.

6. Conclusion

With the rapid development of modern technology, the application of multi-rotor UAVs in the field of firefighting is gaining increasing attention from firefighting departments and related sectors. To maximize the effectiveness of multi-rotor UAVs in firefighting and rescue operations, it requires the joint efforts of all personnel to actively promote technological research, talent development, scenario application, and maintenance and upkeep. Strengthening cooperation and communication with UAVs companies, research institutions, universities, and other relevant organizations is crucial to drive the application and research of multi-rotor UAVs in firefighting, promoting their use in reconnaissance, modeling, and patrol operations, providing technological and informational support for firefighting and rescue work.

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