UAV data monitoring status and future prospecting

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Abstract

UAVs have become the best means of data monitoring and collection in some cases. By describing applications of UAVs in various fields such as agriculture and forestry, sampling and surveying, and rescue and disaster relief, the necessity of UAV technology development and its unique advantages are explained, and illustrate multiple challenges that UAVs currently face. Finally, the development direction of UAV communication technology and the trend of large-scale civilianization of UAVs are proposed, indicating the bullishness on the development of UAV, and proposing the future research plan for using UAVs in ancient architecture restoration and cultural inheritance.

Keywords: UAV, data collection, communication technology

In the era of big data where automation and information technology are booming, all industries are developing in the direction of digitalization. With the in-depth research in various fields, the demand for fast, accurate, and stable operation is getting higher and higher, the demand for data sample collection is richer, the accuracy of monitoring is gradually increasing, and many tasks relying on manpower alone will lead to high cost, high risk, and low-efficiency results.

1. Background

With the development of geomatics and its related industries, the necessity for remote sensing data collection and monitoring has increased dramatically. The earth system science needs comprehensive, macroscopic and timely information guarantee. However, the huge cost and high technical threshold required to establish a complete space remote sensing system have prevented many underdeveloped countries from meeting the requirements.

The launch price of a remote sensing satellite is about ten to hundreds of millions of dollars, and it needs to pass various regulations and approvals to be put into practical use, but the price of a UAV with top remote sensing and mapping technology is only in the range of one thousand to ten thousand dollars. Under such circumstances, the use of UAVs for aerial photography and earth observation platform and data collection means is undoubtedly a novel and optimal solution.

In addition, the use of traditional methods for manual data collection has low efficiency, is time-consuming, and is dangerous, especially in disaster monitoring and prevention. Accurate and rapid access to data support means that the damage caused by disasters can be reduced to a minimum. When using satellite remote sensing for forest fire detection, although its detection range is wide, the accuracy rate is low and requires spending a lot of human and material resources to verify, places, where traffic is difficult, cannot get good results. The traditional ground patrol has high requirements for human resources and threatens the safety of the lives of practitioners. In addition, in the meteorological observation, the traditional temperature and humidity monitoring methods are mostly single-point, on-site manual recording with high costs, and are inconvenient to manage. Unmanned precise ground information collection and disaster monitoring have become another necessity for the development of geomatics information science.

UAVs have become the best means to carry out data collection or monitoring in the above two situations.

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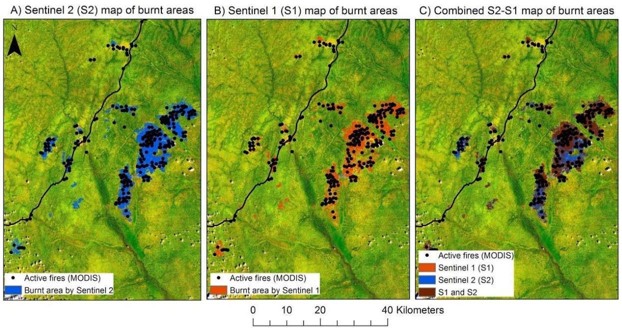

Figure 1: *How satellite image helped detect forest fire in Congo.*

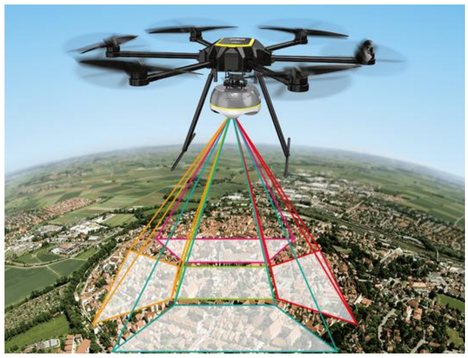

Figure 2: *UAVs for mapping.*

The remote sensing platform built by UAV can obtain high-resolution remote sensing image data in real-time, which can overcome the negative impact of traditional manned aerial remote sensing in encountering long flight time, large maneuvers, bad weather, and dangerous environment, and also can make up for the vacancy of remote sensing information in some specific areas that cannot be obtained by satellite due to weather and time factors, and provide high-resolution images with the multi-angle, wide range and wide field of view. UAVs also have ultra-high resolution and high-frequency acquisition capability, which is more cost-effective and feasible compared to manned aircraft.

The use of UAVs for data collection is also real-time. UAV images can easily provide centimeters or even higher resolution ground information, and there is no contradiction between high spatial resolution and temporal resolution, achieving the dialectical unity of space and time based on low cost. In addition, with the development of computer technology and communication technology, the birth of more lightweight, small volume, and high-precision sensors makes the performance of UAVs improve.

In various engineering research and mapping tasks, UAVs are even the best way for engineers to collect various useful data.

In practice, by allowing UAVs to follow pre-drawn maps on a prescribed route, engineers can easily view relevant data and successfully perform technical surveys and mapping tasks while ensuring safety. In urban disaster relief, UAVs can perform low-level flights to detect casualties and changes in the disaster situation more quickly and accurately. China has now successfully developed a low-altitude unmanned airship surveillance system [1]. This system acquires images more accurately and clearer through innovative and improved camera systems. Compared with traditional information acquisition techniques, the low-altitude UAV detection system is more automated and intelligent, which better improves the efficiency of technical mapping.

2. Applications of UAVs

UAVs are unmanned aerial vehicle, usually known as drones, and have become a new means of collecting and transmitting data by combining them with a wide variety of sensors and communication tools.

The emerging technology of UAVs has entered many fields, and they offer several advantages,safer than aircraft, cheaper than satellite imagery, and more flexible than ground-based sensing and actuation platforms, requiring fewer human intervention, fewer operational hazards, it features autonomous control and a higher level of maneuverability.

UAVs have been used in many applications due to their agility, portability, and air accessibility, they are often used in low-cost and accurate surveillance while minimizing the risk of human intervention and lethal hazards[2]. These include transportation [3], traffic control, surveillance, border patrol, search and rescue [4], disaster prediction, agriculture, and forestry [5], remote immersion through VR, and UAVs are also widely applied to military.

In addition to commercial cases above, many new applications are being implemented in academic study and industry, such as mapping, volcano monitoring, UAV brain control, severe weather warning, plant protection, airborne wind-energy

Figure 3: *UAVs in multiple applications.*

harvesting systems, birds flock robotic grazing, Amazon Prime Air, and UPS drone delivery services [6].

2.1. Agroforestry

In the current development process of agriculture and forestry, UAVs play a great role in estimating and collecting crop information and monitoring and exerting agricultural activities. Such as forestry monitoring, plant protection operations, crop pollination, etc., which cannot be done precisely by traditional means, agricultural drones not only have better operational effects than manual operations but also have greater advantages in terms of operational efficiency, economy, and safety assurance.

Through the high-frequency characteristics of UAV remote sensing, it is possible to obtain time-series multispectral images of a variety of crops for yield and maturity estimation [7].

Using a new UAV remote sensing information platform to obtain crop information and monitor crop growth has become the best means for the development of agricultural data monitoring technology, such as in the use of UAV for crop information acquisition, Fan [8] et al. proposed a platform for managing crop information collected through multi-rotor UAVs, using the Django framework to design an information service system to collect real-time UAV crop information and location information, which can perform a wide range of performance evaluation of crops for sensing and monitoring.

To apply UAVs to traditional farm monitoring and pest detection, Yiannis [9] et al. developed a novel application based on cloud and artificial intelligence that can efficiently analyze and visualize the data collected by UAVs. Using small UAVs equipped with various sensors can automatically create tree inventories and evaluate plant characteristics to survey and assess farmland.

In the direction of application of agricultural activities, the wheels of traditional ground sprayers can roll over cotton plants, breaking branches and hitting or dislodging cotton bolls, causing considerable yield losses. It is more effective to use UAV sprayers, which can enter the field without damaging the crop or soil and operate efficiently, especially when operating in swarms, where their propellers generate strong airflow that facilitates spray deposition and penetration, improves droplet distribution uniformity and reduces drift. A study by Chris [10] et al. compared the efficacy between aerial UAV spraying and traditional ground sprayers that investigated the important operational parameters of UAV spraying. The results showed that UAV spraying was more efficient.

In recent years, with the diversification of society's demand for forest resource information, information collection and resource surveys have become more and more important, and many applications that could not be obtained with better results using satellite images in the past are now well implemented by UAVs. For example, mangrove species identification can be carried out using UAV hyperspectral [11], and invasive alien species can be detected and identified through UAV imaging spectral data, etc., to provide support for ecological environmental protection.

2.2. Surveying and Disaster Relief

UAVs are also irreplaceable new tools in emergency search and relief and geomorphological mapping, disaster damage prediction, and accurate assessment. For example, through UAV tilt photography, 3D information on surface targets can be obtained and 3D modeling of ground targets can be carried out.

Search and rescue methods using UAVs have been put into practical application. Ignacio [12] et al. proposed a UAV human detection system for search and rescue missions, which combines a machine learning architecture with CNN models for human detection by UAVs and establishes secure communication between UAVs and smartphones, allowing highly portable, stable, and cost-effective search and rescue.

Sung [13] et al. proposed a UAV swarm path planning method for maritime search and rescue, using a network-based region decomposition method to convert the search area into a graph consisting of vertices and edges, and then using an algorithm to derive the optimal search path for the UAV swarm to provide effective sea surface search coverage.

UAV-based remote sensing platforms facilitate new scientific discoveries, can provide extreme environmental sampling and data acquisition, and provide first-hand data support for disaster research and prediction, which also contribute significantly to volcanology and earth sciences. Hu [14] et al. proposed a fault-tolerant collaborative navigation framework for UAV swarms capable of performing target tracking tasks for the forest fire monitoring problem and designed a distributed fire monitoring algorithm to track the propagation of large forest fires with high applicability and robustness.

In 2017, a multinational research team used sensor- and camera-mounted UAVs to capture images of the eruption of the Tierra del Fuego volcano in Guatemala, measure related data, and model the dynamic process [15]. After the successful flight detection of five hurricanes in the Atlantic Ocean, NASA has helped to build a fine structure system for typhoons.

Sebastián [17] studied the effectiveness of UAVs for geomorphological analysis in tropical volcanic environments and showed that UAVs can provide high-quality data for the study of tropical volcanoes at low cost and that the use of digital images captured by UAVs can facilitate and improve volcano mapping, characterization, interpretation, monitoring, and hazard assessment, and enhance the study of volcanic geomorphological environments.

UAVs also play a great role in natural disasters and emergencies, and have a significant contribution to the prediction of major natural disasters, in addition to the delivery of supplies and personnel search and rescue. Guang [18] et al. proposed an intelligent detection of marine disasters based on UAV intelligent vision, and constructed a remote sensing feature model for intelligent inspection of marine disasters and a pixel spatial reconstruction model for UAV remote sensing images, using post edge pixel information fusion and image region reconstruction to extract high spatial features.

Figure 4: *UAVs for volcanic surveys.*

2.3. *Military*

UAVs play a critical role in military. In various battlefields, UAVs are required to arrive designated locations without human intervention precisely. Therefore, it is imperative to find a suitable method to solve the UAV autonomous motion planning problem, on this account can improve the mission success rates of UAVs to some extent.

Recently, many researchers have apply deep reinforcement learning (DRL) methods to solvinging the AMP problem and achieved good results [19]. Hu [20] etal. designed a sampling method with double screening from the perspective of sampling and combined it with the deep deterministic policy gradient (DDPG) algorithm to propose the related empirical learning-DDPG algorithm.

With the advancement of sixth-generation (6G) communication systems, UAVs have emerged as a promising new application by exploiting more favorable line-of-sight propagation. However, exploiting the maneuverability of UAVs to resist interference is a new challenge for UAV-ground communication. Zhou [21] et al. studied the trajectory planning problem in UAV communication systems and developed an iterative algorithm with the help of the S-process and successive convex approximation methods.

In addition, with the increase in mission complexity and UAV autonomy, UAV swarm systems have gradually attracted the attention of many researchers. Zhao [22] et al. proposed a distributed coordination control scheme for UAV swarms based on heterogeneous roles to achieve formation control.

2.4. Road safety and transport

Road traffic accidents are a global problem and are considered one of the most significant threats to public health. UAV traffic surveillance is a better alternative to traditional labor-intensive and complex surveillance systems due to the easy deployment, dynamic design, low maintenance cost, high mobility, and fast response of UAVs.

Navid [23] et al. proposed a UAV-based intelligent monitoring traffic surveillance system for speed limits and traffic violations, which uses 5G technology to effectively reduce accidents and fatalities by overcoming the limitations and vulnerabilities of the original traffic system.

Ahmed [24] et al. proposed a new computational offloading/shared strategy for UAV-assisted road traffic surveillance scenarios for data processing and user response time, computational consumption, cellular communication cost, and computational cost as system metrics to optimize system performance.

Zhu [25] et al. proposed a UAV-based approach to detect and simulate pedestrian movements at frequent collision intersections. The method uses deep learning methods for high-resolution extraction of pedestrian, bicycle, and vehicle motions to build a model for saving pedestrian lives based on pedestrian trajectories, which effectively reduces the accident rate.

UAVs can also play a role in transportation. The use of UAVs for material transportation in post-disaster sites and complex geographic environments that are difficult to reach by humans can not only deliver materials to their destinations in a more timely manner but also reduce the consumption of manpower.

Wang C [26] et al. used deep reinforcement learning to achieve autonomous navigation of UAVs in large-scale complex environments, using an online DRL algorithm that directly maps UAVs and apos, and the cross-obstacle transportation results are more effective.

Huang [27] combined deep reinforcement learning into the UAV navigation system by integrating multiple-input multiple-output (MIMO) techniques, established a deep q-network, and proposed a learning mechanism to handle DQN to optimize UAV navigation by selecting the optimal strategy that enables the UAV to cover the quickly select the quickest transport path.

Figure 5: *UAVs for delivery.*

Kwak [28] etal. proposed a flight control algorithm for UAVs to plan the flight path by using a hierarchical A* search algorithm based on graphically generated flight paths by taking images at multiple surveillance points, thus enhancing the speed and accuracy of UAVs in the transport process as well as reducing the complexity of the flight path.

3. Technical challenges of UAVs

Despite the rapid development of current UAV technology, there are still many challenges to overcome. Firstly, there are still many technical barriers for UAVs to be broken through, such as communication technology, battery life, how to reduce the size while maintaining perfect performance, and how to achieve intelligent control. Secondly, the potential safety hazards faced by UAVs are very serious, and the malfunction of the obstacle avoidance function of the drone will affect the safety of the UAV itself and the surrounding environment. Thirdly, the policy system and market supervision of UAVs still need to be standardized.

3.1. Technical barriers to UAVs

A. Challenges of Communication Technology

UAVs rely heavily on GPS and communication systems. UAV navigation requires GPS in conjunction with an inertial navigation system (INS) and relies on GPS for positioning and timing information. Precise positioning is very important for UAVs for many purposes. For example, in UAVs used for express delivery services, if the positioning is wrong, the delivery destination does not match the destination, which will lead to business errors. In addition, UAVs that use multiple sensors to perform intelligence, surveillance, and reconnaissance missions also require precise positioning.

Papachristos et al. [29] proposed an integrated approach for autonomous navigation and mapping in underground mines using aerial robots. However, the unique geography of underground mines makes GPS ineffective, and the sensors are severely degraded due to factors such as darkness, dust, and smoke. At the same time, some very narrow geometries also present strict navigation conditions. The combination of difficulties makes the UAV unsatisfactory for this task.

B. Challenges of size and battery life

For UAVs, how to balance battery life with volume and weight is another technical problem. The battery life of micro-UAVs is only dozens of minutes [30], which greatly limits the range of use of UAVs. Furthermore, battery failure can have catastrophic consequences [31]. Under the premise that there is no fundamental change in power storage technology, when the total amount of batteries increases to a certain value, the improvement in battery life will inevitably begin to weaken. For example, in the iteration of DJI's series UAV products, from 27 minutes of the Royal Pro to 31 minutes of the Royal 2 to 34 minutes of the Royal Air2, the slight increase in battery life of a few minutes has been studied by the engineering team for several years.

3.2. Security

The safety of UAVs is still a major problem to be solved urgently. Many uncontrollable factors in the flight environment, such as pedestrians suddenly appearing during low-altitude flights or hard-to-find thin electric wires around, will affect the UAVs. When the UAVs are damaged, the rapidly rotating propeller also causes damage to objects and humans in the environment. At present, the most popular technologies used in obstacle avoidance for UAVs are infrared sensors, ultrasonic sensors, laser sensors, and visual sensors, but they all have their blind spots or shortcomings. Douthwaite et al. [32] conducted a critical analysis of the above-mentioned UAV obstacle avoidance methods, and proposed several evaluation schemes for sensor uncertainty and increasing obstacle avoidance difficulty, but were still unable to obtain a universal obstacle avoidance method. Carrying multiple sensors will make the weight and volume of the drone too large, which is a big challenge to its endurance. In addition, there are still major problems in the boundary processing of the obstacle avoidance function. For example, the obstacle avoidance method of binocular vision can work when the line of sight is good, but cannot be accurately implemented when there is dust.

3.3. Policy and Administration

The unregulated use of civil UAVs will threaten the public safety of core locations such as civil aviation, power stations, railways, and hazardous chemical storage points, and will also cause considerable harm to the safety of citizens' personal, property, and privacy. At present, most of the regulations that have been issued around the world remain at the level of departmental regulations, which have not yet risen to the level of laws, and lack sufficient binding force. The lack of detailed management regulations and implementation rules, and the lack of clear legal provisions to regulate the flight activities of UAVs in low-altitude airspace are all current management problems.

4. Prospect of UAVs

Over the next decade, researchers will utilize artificial neural networks [33], deep learning [34], and machine learning [35] to optimize UAV communication networks, as these applications will further highlight the advantages of UAVs. Implementing artificial intelligence in location verification, route management [36], and estimating mission success rates [37] presents great challenges.

When it comes to designing an AI-based approach for UAV communication systems, the first challenge is choosing the right AI technology. Since the UAV communication system is a more complex multi-dimensional network than the existing ground communication network, how design a suitable artificial intelligence technology needs further exploration. In addition, when deploying AI-based solutions, the computation consuming time and transmission delay between the drone and the ground station can have a bad impact on network performance.

As AI involves more computation than traditional methods, reducing computational complexity is required so as to accelerate computational efficiency when using AI to optimize the performance of networks. Furthermore, to deploy AI-based strategies, Wang [38] proposed a novel UAV communication network, in which UAVs have visible light communication capabilities, and communication is highly dependent on ambient lighting. A machine learning algorithm combining Gated Recurrent Units (GRUs) and Convolutional Neural Networks (CNNs) is used to optimize UAV deployment and minimize the total transmit power. In future research, the problem of building efficient and reliable AI-based UAV communication systems should continue to be addressed.

In the development of future drone networks, LoRa and 6LoWPAN have become potential instruments for short-range UAV communications. Challenges of frequency interference, rate adaptation, high-altitude performance can be addressed by computer control network [39]. However, it can be observed that power of UAVs, connectivity between UAVs, and the aircraft's inflight stability will all need to be improved in the future. Total flight time, control of dense geographic areas beyond the line of sight etc. also need to be improved.

Future cellular-connected drone networks will also find applications. The use of cellular connectivity enhanced channel characteristics for high-altitude UAVs, and communication link characteristics such as uplink and downlink traffic management will be open issues for future UAV communications [40].

The participation of 5G and new communication methods, such as non-orthogonal multiple access (NOMA), industrial IoUAV, etc., have achieved good results in terms of energy saving, fast integration, and ease of adoption [41]. Researchers are currently working on precise models of cellular-connected drone networks using different technologies.

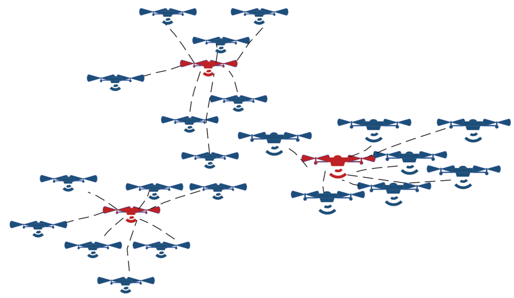

Figure 6: *UAV clustering.*

Finally, future drone communications that can rely on UAVs integrating 5G and IoT technologies will have a major impact on smart city commerce and safety. However, it is important to consider the rules and regulations related to usage in terms of application. In enhancing drone communication cognition, artificial intelligence, communication technology, and security will play an important role in future UAVs.

The macro trend of the future development of UAVs is from the application in the military field to the development of civilian use.

In addition to being used as military weapons, it will expand to all aspects of people's lives, such as farming labor in agriculture and forestry, cargo transportation in factories or communities, ocean, and meteorology monitoring, disaster prediction, etc., to make people's life more convenient and the living environment safer. The specific development direction forecast can be summarized into the following four aspects.

1. *Clustering*. Micro-UAV swarm operation is a major direction of future UAV development. The multi-machine cooperative operation can greatly improve operation efficiency. At present, the information interaction and task cooperation planning between micro-UAVs have become a research hotspot.

2. *Intelligent*. The intelligence level of UAVs represented by autonomous control will be greatly improved in the future. After adopting artificial intelligence and swarm intelligence optimization technology, UAV fleets can

autonomously complete a series of actions such as automatically finding targets, determining targets, selecting suitable means of operation, and coordinating execution from hundreds of kilometers or even thousands of kilometers away.

3. *Integration*. In the future, UAVs are developing in the direction of system integration and comprehensive sensing. There is no longer an obvious classification. One UAV can complete an integrated task that integrates multiple individual tasks. At the same time, the UAV data link can be quickly shared with manned fighter jets, and their respective labors can be divided to meet the needs of different tasks.

4. *Civilization*. According to The US Army UAS Roadmap (2010-2035) [42], the application scope of UAVs in the military field will be further extended to more types of combat missions such as C3I command and control, air combat, aerial refueling, and air transport, and gradually replace manned aircraft. In the civilian field, with the deepening of the awareness of the application value of UAVs, the application of UAVs in remote sensing mapping, border, and coastal defense, forest fire prevention, pipeline patrol, police law enforcement, etc. The trend of rapid development. In the future, the global market demand for civilian UAVs will increase rapidly at an average annual rate of nearly 30%.

5. Comment & future research

After the above review, we can feel the vigorous development of UAV technology and applications. We have learned that the four most important components of UAVs are, the automatic flight device, propulsion device, sensor, and load device. Under different device configurations, UAVs can perform different tasks. Among these tasks, what interests us most is the ability of UAVs in data collection. With the increasing development of sensor technology and image processing technology, there are no devices equipped with humans and machines are also becoming more and more lightweight and advanced, enabling faster, more accurate, and more automated monitoring and detection tasks.

Combining drone technology and interest, an interdisciplinary drone application direction attracted us: the application of UAVs in the repair and protection of ancient buildings. Our motherland China is a country with a long history. More than 5,000 years of history have brought splendid cultural sites. However, it is sad that there are many ancient buildings left in various places that are not well protected. After conducting on-the-spot investigations on several typical cities in China, we found that no matter in less developed provinces such as Anhui, or economically developed areas such as Shanghai and Xi'an, many people are using manpower to monitor and repair ancient buildings. The main reasons for its protection are:

1. In most economically backward provinces, ancient buildings are in disrepair and hidden in deep mountains and old forests. Exploration and testing require a lot of manpower, and safety cannot be guaranteed.

2. Unless carefully identified by architectural and historical professionals, it is difficult for the human eye to detect wear and tear from some natural factors.

3. Due to the limited number of professionals and the vast land in China, it is difficult to assign teams in one place to conduct frequent monitoring at regular and fixed points, and the collection of big data relies on manual input, making it difficult to integrate into a system for unified analysis.

4. Since some ancient buildings have been opened as tourist attractions, the behavior of tourists has also added many uncertain factors to the protection of ancient buildings, and it is impossible to accurately capture each time they are destroyed.

However, the characteristics of UAVs can be used to solve the problems encountered in the protection of ancient buildings under certain conditions, such as UAVs can replace manpower to explore dangerous areas; after comparing pictures, machine learning algorithms are used in unmanned aerial vehicles.

Figure 7: *UAVs for historic building conservation.*

Human-machine camera capture can solve the problem of small damage that is difficult to find, and the flexibility of UAVs can also take into account the blind spots of traditional cameras to conduct a comprehensive search for ancient buildings; in the special inspection of ancient buildings, UAVs After being applied to the market, it will solve the problem of insufficient professionals on a large scale, and allocate UAVs for monitoring and data uploading, that is, data can be analyzed and updated in real-time across the country.

We believe that the development of UAVs will develop into a very broad field under the trend that technical barriers are gradually being broken and policies are becoming more and more standardized. While facilitating people's lives, it can also allow the inheritance and protection of culture.

6. Conclusion

Nowadays, UAVs have been applied in all walks of life, especially the advantages of data collection are obvious, which has become an important technical research direction that has attracted much attention. This attention comes from the pull of application requirements on the one hand, and the challenge of this technology on the other hand. The current technical barriers will not become a stumbling block for the development of UAVs, but it means that the development of UAVs still has huge potential in technology, making great strides toward the trend of intelligence, integration, clustering, and civilian use. With the continuous application of artificial intelligence and other technologies in UAVs, the performance of UAVs will become more and more advanced. It is foreseeable that UAVs will be widely used in more scenarios.

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