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Application of UAV Remote Sensing Technology in Urban Environments

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Abstract. This paper innovatively constructs a multi-dimensional analysis framework of "technology-application-policy-trend", and systematically elucidates the theoretical contribution and practical value of unmanned aerial vehicle (UAV) remote sensing technology to drive urban intelligent transformation. In the technical dimension, the synergistic mechanism of diversified evolution of hardware platforms and high-performance sensors is revealed, and the accuracy and efficiency bottlenecks of large-scale urban modeling are broken. In terms of application, the core role of this technology in the paradigm change of urban dynamic monitoring is demonstrated, and the timeliness and scientific nature of spatial decision-making are significantly improved. In the governance dimension, for the first time, it integrates policies, regulations and ethical constraint analysis, and proposes a systematic solution to airspace management fragmentation and privacy risks. In terms of trends, it pioneers the industrialization path of edge intelligence and Remote Sensing as a Service (RSaaS), providing a theoretical paradigm and technical route for the sustainable development of smart cities. This study fills the academic gap in the research of multi-dimensional system research on urban application of unmanned aerial vehicles (UAVs) and lays the theoretical foundation for collaborative innovation between industry, university and research.

Keywords: Remote Sensing, Smart City, Multi-Dimensional Framework, Synergy Mechanism, Policy Bottlenecks.

1. Introduction

Global urbanization is reshaping cities at an unprecedented rate. Today, more than half of the population (55%) is already concentrated in cities, and the United Nations predicts that this proportion will climb to 68% by 2050 [1]. As the core of economic activities and public governance, how to achieve refined management and ecological protection becomes a key challenge for sustainable development.Especially in sudden disaster response and dynamic environmental monitoring, the need for real-time and accurate spatial data is becoming more and more urgent.

Traditional remote sensing methods expose obvious shortcomings in urban monitoring.Although satellite imagery covers a wide range, it usually takes 5 to 15 days to revisit the same area due to orbital limitations, making it difficult to capture instantaneous events such as the spread of illegal buildings or sudden pollution Although manned aerial remote sensing has a higher resolution, the

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cost of a single flight is as high as tens of thousands of yuan, and it is strictly controlled by airspace, so it cannot achieve normal monitoring [2, 3]. This dilemma of "data lag" and "lack of details" is particularly prominent in heat island effect monitoring, where traditional methods are difficult to distinguish between temperature differences at the block scale, resulting in a lack of pertinence in ecological regulation measures.

The rise of drone technology provides new ideas for solving these problems.With a low-altitude altitude of 50 to 500 meters, the drone can effectively avoid cloud interference and obtain centimeter-accurate 3D data by mounting a hyperspectral camera or lidar.Taking the construction of Shenzhen's digital twin city as an example, the unmanned aerial vehicle (UAV) cluster completed the fine modeling of a 200-square-kilometer urban area in just 3 days, with an accuracy of 0.1 meters, providing a reliable basis for urban planning [4]. In the emergency rescue in Zibo, Shandong Province, the real-time post-disaster images returned by drones improved the rescue dispatch efficiency by 40% [5]. Compared with traditional methods, drones not only reduce costs by more than 60%, but also shorten the response time to several hours, significantly improving the feasibility of urban dynamic monitoring [6].

However, drones still face multiple obstacles in urban applications.At the technical level, the accuracy of multi-sensor data fusion is insufficient [7], which affects the reliability of ecological parameter inversion.In terms of policy, the airspace approval process is complex (e.g., most cities in China require 72 hours of advance application) [8], and data privacy protection standards are not unified (e.g., the EU GDPR strictly restricts image data) [9]. In practical applications, electromagnetic interference in high-density urban areas and autonomous obstacle avoidance capabilities in complex terrain are still unsolved problems [10]. Current research mostly focuses on a single technology or scenario, and lacks systematic integration of technology, application and policy, which restricts the industrialization of technology.

Based on this, this paper systematically sorts out the technological evolution, application scenarios and cutting-edge trends of UAV remote sensing in the urban field, and constructs a multi-dimensional analysis framework, aiming to provide theoretical reference for the academic community, point out the direction for industry practice, and promote this technology to play a greater value in smart city construction.

2. The basic evolution of UAV remote sensing technology

2.1. Hardware platform and sensor innovation

The innovation of UAV platform and sensor technology is the cornerstone of the development of urban remote sensing:

Fixed-wing drones have a battery life of ≥ 120 minutes, which is suitable for large-scale censuses; Multi-rotor VT (vertical take-off and landing) models can flexibly shuttle between building complexes; Hybrid-wing models balance flight time and maneuverability, making them ideal for infrastructure inspections.

LiDAR point cloud density reaches 2000 points/square meter, capturing the details of cracks in building facades; Hyperspectral imagers can identify a surface temperature difference of 0.05°C at an altitude of 200 meters, which can support the study of heat island effect (Table 1) [11].

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Table 1. Comparison of the performance of mainstream sensors in urban remote sensing

Sensor type	Spatial resolution	Applicable scenarios	Technical limitations
Hyperspectral cameras	5cm@100m	Vegetation health monitoring	It is greatly affected by light
LiDAR	10cm@150m	3D modeling	Rain and fog penetration is poor
Infrared thermal imager	0.5°C thermal sensitivity	Energy leak detection	Temperature calibration is required
synthetic aperture radar	0.1m	Deformation monitoring	Data interpretation is complex

2.2. Data transmission and processing algorithms

Real-time transmission and intelligent processing constitute an important link in the urban application of UAVs:

Using high-ratio lossy compression techniques (e.g., EBCOT-like algorithms and MPEG-2 standards), the compression ratio can reach 30:1, considering both efficiency and quality [12]. Combined with multimodal transmission link C-band link and satellite data transmission system), supplemented by on-board storage and backup to ensure data security [13]. 5G edge computing makes modeling delay less than 1 second (Jinan Smart Urban Management Platform)

Lightweight AI model, Wuhan's "sky-ground network" system deploys a lightweight model on the UAV side, which increases the efficiency of illegal building identification by 3 times and reduces bandwidth occupation by 90%; The SFM-MVS algorithm controls the 3D reconstruction error within 0.05 meters.

2.3. Multi-machine collaboration and intelligent decision-making mechanism

UAV swarm technology is moving from proof-of-concept to engineering practice: multi-source information fusion needs to process multi-sensor data, cope with complex environments, and provide information for decision-making, involving multi-sensor information hierarchical processing, feature extraction, etc.For complex unknown areas, target recognition and situational awareness technology can be used to achieve target detection and identification at low cost, facing data processing and accuracy challenges, and new algorithms are needed to improve the efficiency of cluster decision-making and task execution.The UAV swarm communication network is regarded as a self-organizing network, and the communication architecture (centralized, distributed, etc.) and optimization are studied to cope with different mission scenarios, solve the communication bottleneck of a single UAV, and ensure information interaction [14].

3. In-depth analysis of urban application scenarios

3.1. Smart city management

Urban planning and design are based on efficient surveying and mapping to assist in building layout, road network optimization, and green coverage analysis [15]. Building density and land use monitoring dynamically tracked the changes in building density in the central area of the city and classified land use [16]. The analysis of the transportation network combines UAV images and GIS data to extract road geometric features, traffic distribution, and accident hotspots to optimize transportation facility planning [17].

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3.2. Urban ecological environment monitoring

Atmospheric environment monitoring is the use of high-precision sensors to monitor pollutants such as VOCs and PM2.5, and quickly identify pollution sources (such as illegal emissions at night) [18]. Soil and land degradation are detected to support land restoration planning by assessing soil moisture, salinization, and erosion [19]. Monitor the water environment, analyze water temperature and pollutant composition in real time, monitor illegal discharges by enterprises, and optimize water resource management [20].

3.3. Urban emergency response and public safety

UAV technology plays an indispensable role in disaster assessment, such as the Shaoguan flood in Guangdong, where the UAV cluster completed 3D modeling of the affected area within 4 hours, and the life detection efficiency increased by 60% compared with 2018. At the same time, public safety prevention and control also needs the support of drone technology, and the flood control system of Chongqing Liangjiang New Area uses thermal imaging drones to identify people stranded on the riverside, reducing drowning accidents by 70% year-on-year in the summer of 2025 (Table 2).

Table 2. Efficiency indicators of UAV in emergency scenarios

Application type	Response time	Data accuracy	Decision-making improvement
Flood disaster assessment	< 2 hours	0.1m DEM	Rescue Efficiency↑40%
Identification of seismic structural damage	< 3 hours	Crack identification 2mm	Dangerous house judgment accuracy ↑35%
Hazardous chemical leakage monitoring	real time	Gas concentration 0.1ppm	Evacuation Range Accuracy ↑50%

4. Methodology, policy and ethical challenges

4.1. Technical bottlenecks

The complex urban environment poses a severe test for UAV remote sensing technology: the insufficient accuracy of multi-source data fusion has become the core constraint, the optical-LiDAR point cloud registration error in high-rise building areas is as high as 0.5 meters, and the mismatching rate in dense areas of glass curtain walls is as high as 15%; The environmental adaptability defect further amplifies the operation risk, and the GNSS (Global Navigation Satellite System) rejection scenario has a positioning drift of 3-5 meters, and the superimposed electromagnetic interference leads to an out-of-control accident rate of 0.8 times/1,000 sorties. The contradiction between endurance and load exposes the shortcomings of system design, with the endurance plummeting from 45 minutes to 20 minutes during full-load flight, and even hydrogen fuel cell solutions face industrialization obstacles with a 300% cost surge. These bottlenecks collectively point to the need for collaborative innovation between lightweight hardware and intelligent adaptive algorithms.

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4.2. System, regulations and policy restrictions

The fragmentation of the global policy framework seriously hinders the implementation of technology: the fragmentation of airspace management mechanisms constitutes the primary obstacle, and the institutional gap between China's 72-hour approval system and the real-time filing model in Europe and the United States. Data compliance risks continue to intensify due to legislative differences, such as the EU GDPR defining drone images as biometric data, and China's Personal Information Protection Law requiring separate consent for face collection in public areas, resulting in serious obstacles to the cross-border flow of data of multinational enterprises.

4.3. Ethical risks and social acceptance

67% of residents in a community in Beijing resisted drone inspections, and it was difficult to eliminate privacy risks while operating at low altitudes below 10 meters. Algorithmic bias and social equity issues, such as the accuracy of building recognition in the slums (82%) is lower than that of upscale neighborhoods (94%), and the density of drones in Manhattan, New York, is 6 times that of the Bronx. These contradictions warn that technological innovation that lacks social acceptance will lose the foundation of sustainable development.

5. Future technology trends and development paths

Edge intelligence three-level architecture: Shanghai Pudong New Area pilots the "end-edge-cloud" architecture, reducing the delay of traffic event recognition to 0.8 seconds and reducing energy consumption by 75%; 6G synaesthesia integration: The terahertz communication test achieves a delay of 0.1ms, providing the possibility of autonomous obstacle avoidance in complex scenarios.

Autonomous decision-making system: The success rate of obstacle avoidance of the enhanced learning path planning algorithm in Wuhan power grid inspection is 98%; Digital twin linkage: Shenzhen's "city brain" is connected to real-time data from drones, and the prediction accuracy of heavy rain and waterlogging reaches 30 minutes.

International standard construction: ISO/TC20/SC16 working group formulates airspace classification (Class G), airworthiness certification (Class IV), and data security (ISO 27090) standards; China-led "urban low-altitude intelligent networking" standard is supported by ASEAN; Business model innovation: The remote sensing as a service (RSaaS) model is applied in Yuhang District, Hangzhou, and the annual cost is reduced by 40% compared with the self-built team; The insurance industry dynamically adjusts premiums through drone risk assessment models.

6. Conclusion

UAV remote sensing technology is profoundly changing the urban management model, and its value core lies in breaking through the traditional remote sensing dilemma of "data lag - lack of details". In the future, it is necessary to focus on breaking through multi-sensor adaptive fusion algorithms and anti-interference navigation modules, establish a "red-yellow-blue" three-level airspace approval system, and formulate national standards for data desensitization. When drones evolve from simple "air perception terminals" to "urban smart nodes" with autonomous decision-making capabilities, their role will undergo qualitative changes - no longer limited to data collection tools but become the core engine driving the adaptive optimization of urban systems. This transformation requires collaborative innovation from all parties involved in industry, academia, research and application: academic institutions should focus on breaking through the theoretical bottleneck of intelligent

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spatial information processing, industry should accelerate the engineering transformation of technological achievements, and policymakers should build a flexible and hierarchical regulatory framework. Only by forming a three-dimensional drive of "theoretical innovation, technological breakthrough, and institutional guarantee" can the strategic value of UAV technology in smart city construction be fully released.

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