UAV technology application and economic benefit assessment for urban ecological environment monitoring and decision-making

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Abstract: This paper illustrates the application of drone technology in monitoring of urban eco-environment and its economic benefit assessment. From the systematic analysis of the development overview, the classification and practical application of UAV technology, this paper shows that the UAV technology has the advantages of high efficiency, flexibility, and low cost, which may provide the high resolution of spatial and temporal resolution data with significant improvement of the efficiency and effectiveness of the environmental monitoring of a single accuracy. The showed cost-benefit analysis, based on real project data, showed that, compared to classic methods, drones have significantly lower initial costs, costs of maintenance, and operating costs, with a higher economic benefit estimation for return on investment and net present value. Drones have shown wide application potential in air quality monitoring, water environment monitoring, disaster management, etc., providing reliable technical support for environmental monitoring. This study summarizes the main advantages and economic benefits of UAV technology in urban environmental monitoring, and provides a theoretical basis and practical guidance for its further promotion and application.

1. Introduction

1.1 Research background and importance

In recent years, with the rapid acceleration of urbanization and the deterioration of environmental problems, the traditional method for monitoring the ecological environment has been unable to meet the needs of real-time, accurate environmental data in modern cities. Drones, otherwise known as unmanned aerial vehicles, have gained immense importance for environmental scientists and urban managers due to their low cost, high flexibility, and high-resolution ability of capturing data[1]. The implementation of drones in urban areas would assist in effective data collection of the urban heat island effect, the quality of air, and the level of greenhouse gas emission. In fact, it will help in simulating the development of the predictive model for climate scenarios with changes in artificial intelligence to mitigate and adapt the processes of the climate[2][3].

The advantages of drone technologies in environmental monitoring are obvious. Ground sensors and satellite remote sensing belong to the traditional methods for the detection of the ecological environment, with excellent practicability, wide development prospect, and so on; however, they are often limited by spatial resolution and temporal resolution. The drones are able to fill the gap in the traditional ways because they can fly at low altitudes and provide data with a high spatiotemporal resolution[4]. Besides, unmanned systems reduce human interference in the process of monitoring the ecological environment of a city and improve the accuracy and reliability of data[5].

The applicability of drone technology is not strictly in the monitoring of environmental conditions; it also has great potential economically. The introduction of drone technology could substantially reduce the cost for monitoring the environment, increase working efficiency, and further improve the scientific quality of the environment and resource scientific decisions in relation to governance [6]. For instance, the drones will simplify the acquirement of large-scale information within a very short time, thereby saving the cost aspect pertaining to labor and materials used. On the other hand, the fast rate of processing data may make the identification and solution of derivatives of environmental

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problems very fast [7].

1.2 Research objectives

This paper explores the use of drone technology in monitoring ecological habitats within urban settings and appraises the economic gain from such monitoring. Against this general objective, the specific objectives of the study come into focus.

Systematic review on the development status of drone technology and its application in environmental monitoring: A general history of developing drone technology, its classification, and concrete application in terms of urban environmental monitoring can be realized through the literature review.

Current Overall Situation of Urban Ecological Environment Monitoring and the Advantages Gained through the Use of Drone Monitoring Technology in Comparison with the Established Monitoring Method: The spatiotemporal resolution, accuracy, and real-time performance of the monitoring data before and after drone surveillance technology was introduced.

We need to analyze typical application cases of drone technology in environmental monitoring and evaluate their actual application effects in urban heat island effect, air quality monitoring, greenhouse gas emission monitoring, etc.

The Economic Benefit Evaluation on the Application of Drones Technology: Adopt cost-benefit analysis to evaluate the economic value of drones technology for urban environmental monitoring and prove that it is cost-effective through case analysis. 5) Challenges and Future Development of Drone Technology in Environmental Monitoring: Study the legal, regulatory, and technological difficulties of drone technology and suggest future development and response. Confirmation of the above research objectives will provide a systematic theoretical foundation with practical guidance for applying drone technology in urban ecological environmental monitoring, with a scientific basis for related policy-making.

2. Literature review

2.1 Overview of the development of drone technology

Over the past decade, drone technology has rapidly developed from its military use to a wide range of civilian applications, including agriculture, environmental monitoring, construction, and transportation. The two main aspects of developing drone technology are hardware and software. More and more attention has been paid to lightweight design and the realization of multiple functions on the hardware side [8]. A small-sized drone (e.g., micro drones, unmanned aerial vehicles, etc.) has gradually become the mainstream in the market. The drones are not only equipped with a high-precision flight control system, but they also come with other sensors that support different applications, such as high-resolution cameras, infrared sensors, LIDAR, and so on. On the software side, with the help of artificial intelligence and machine learning algorithms, the level of intelligence of the drone is greatly increased [9]. Intelligence level of the drone through artificial intelligence and machine learning algorithms, in fact, shall be increased to a large extent. With the help of artificial intelligence and machine learning algorithms, the drone might be able to achieve quite advanced functionality, like autonomous flight, obstacle avoidance, and target detection [10].

The development of drones has also benefited from the integration of geographic information system (GIS) technology. The combination of drones and GIS makes spatial data collection and processing more efficient and accurate. This technological advancement not only reduces the cost of data collection, but also improves the real-time and accuracy of data, providing strong support for urban planning, disaster management, and the development of smart cities [11]. In the development of drones, the formulation of laws and policies has also played a key role. Governments of various countries have gradually improved the use specifications and regulatory measures of drones to ensure the safe and legal use of drones in different environments [12].

2.2 Research on the application of drones in environmental monitoring

The use of drones for environmental monitoring is increasing at a rapid rate. Drones have a high efficiency, versatility, and low cost; they play a very important role in environmental science research and management. For example, they can cover large areas of interest and hence make it possible to collect data of very fine detail over large areas without any contact with the ground, thereby greatly improving efficiency and precision in monitoring the environment [13]; for example, drones may be used to monitor an urban heat island effect by carrying out infrared sensors to collect city surface temperature data for analysis of the spatial distribution and change trends of urban heat island effects [14]. Drones may also be used in monitoring air quality and its pollution sources that provide real-time concentration data for atmospheric pollutants, offering a scientific basis for the disposal of environmental pollution [15].

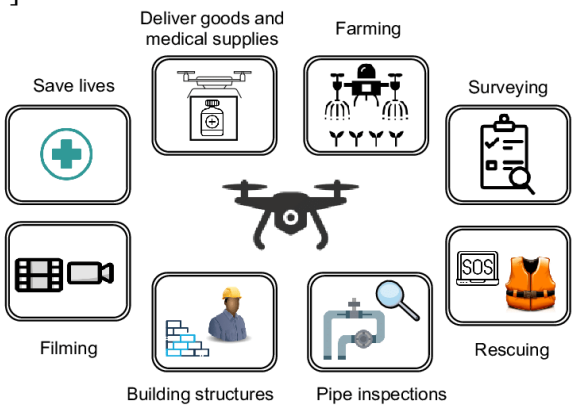

Figure 1: Application of UAVs in various fields [22].

Drones are also widely used in water environment monitoring (as shown in Figure 1). The drones are equipped with multispectral and hyperspectral imaging equipment, through the monitoring of suspended solids, algae, and other pollutants in the water body, to carry on the evaluation of water quality. Furthermore, high-resolution remote sensing images collected by the drone can be used for real-time forest and ecosystem monitoring to follow up the changes in forest health, biodiversity, and vegetation cover change rates [16]. A newly popular application in drones is disaster management: the drone facilitates swift entry into the disaster area right after a disaster, conducts real-time shooting, data analysis, disaster damage assessment, and disaster-assistive decision-making in regard to reconstruction and rescue work [17].

2.3 Related research on economic benefit evaluation

The application of drone technology has not only made significant progress in technology, but also shown great potential in economic benefits. The application of drone technology can significantly reduce the cost of environmental monitoring, improve work efficiency, and promote the scientific and refined management of environmental governance and resources [18]. For example, in the agricultural field, drones can be used for precision agricultural management. Through efficient data collection and analysis, they can optimize the planting and management of crops, improve the efficiency and yield of agricultural production, and reduce the use of pesticides and fertilizers, thereby maximizing economic benefits [19].

In urban planning and construction, the application of drones has also shown significant economic benefits. Through the high-resolution images and three-dimensional modeling technology of drones, data on urban infrastructure can be quickly and accurately obtained, assisting urban planning and design, and reducing the time and cost of traditional surveying and mapping methods [20]. In addition, the application of drones in the fields of logistics and transportation is becoming more and more extensive. Drone delivery services not only improve delivery efficiency and reduce labor costs, but also reduce traffic congestion and carbon emissions, providing new solutions for the sustainable development of cities [21].

3. Current status of urban ecological environment monitoring

3.1 Traditional monitoring methods

Traditional monitoring methods of the urban eco-environment include the ground monitoring stations and satellite remote sensing. Most ground monitoring stations are established in fixed sites. Monitored by a variety of sensors, the monitoring stations can monitor in real time the states of environmental parameters including air quality, water quality, and noise. The monitoring stations may have high-precision data, but the coverage is small, and it is difficult to fully reflect dynamic changes in the urban environment. Besides, it is expensive to build and maintain ground monitoring stations. The spatial resolution of data collection is low, and the spatial resolution is low, which is not timely for changes at the level of the microenvironment. Satellite remote sensing technology uses remote-sensing equipment carried by in-orbit satellites to obtain plenty of environmental data over a large area. If the coverage is large, the temporal resolution will be low and strongly controlled by weather and the atmosphere, which is hard to provide real-time monitoring data.

3.2 Urban Ecological Environment Monitoring Indicators

The monitoring indicators of the urban ecologic environment mainly include the air quality monitoring index, the water quality monitoring index, the noise level index, the land pollution index, and the biodiversity index. Air quality monitoring is generally carried out with respect to the concentrated content of pollutants, such as particulate matter, sulfur dioxide, nitrogen dioxide, and ozone. Water quality monitoring is mainly done for suspendedness, dissolved oxygen, chemical oxygen demand, and harmful substances. Monitoring of the noise level usually indicates the degree to which surrounding sounds reach in terms of the amount of decibels and generally calculates the degree of sound source behavior. Soil pollution monitoring generally involves testing heavy metals, organic pollutants, and other harmful substances in the soil. And biodiversity monitoring tracks and records changes in the species, as well as the number of changes in the plants and animals in the city, to evaluate the situation of the ecosystem. All indicators' monitoring provides a scientific foundation for urban environmental management and the formulation of policies.

3.3 Advantages of UAV Technology

UAV technology has significant advantages in urban ecological environment monitoring. Drones first provide the opportunity to flexibly, quickly, and cheaply cover a large-scale area to obtain high-resolution environmental information, which fills the void in the incompleteness of ground monitoring station information collection and satellite remote sensing and other monitoring information at present. Second, drones are equipped with many sensors, including a high-definition camera, infrared sensor, and lidar, which can monitor and analyze various environmental parameters of the urban environment in real time, such as air quality, water quality, and vegetation coverage. Besides, the drone is low in cost and easy to manipulate and move. It is suitable for manipulating in a great quantity of complex and dangerous environments, such as high-altitude buildings and disaster-stricken areas. The functions of autonomous flight and intelligent navigation of the UAV increase the efficiency and accuracy of data collection, providing technical support for dynamic monitoring and management of the urban ecological environment.

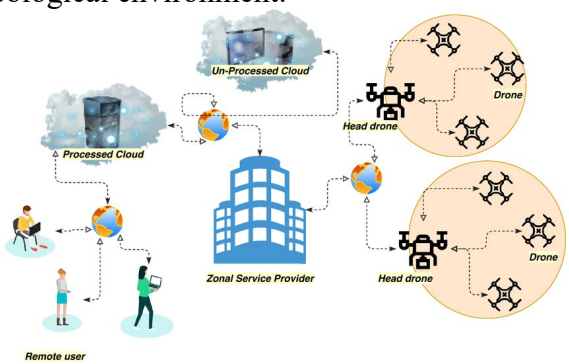

Figure 2: Internet of Drones (IoD) network architecture

Figure 2 shows an Internet of Drones (IoD) network architecture [23], which includes multiple drones, regional service providers, and cloud processing units. The architecture coordinates the tasks of each drone through the head drone, transmits the collected data to the regional service provider, and finally uploads it to the cloud for processing and storage. This architecture can achieve efficient data collection, transmission and processing, providing technical support for urban ecological environment monitoring.

4. Economic Benefit Evaluation

4.1 Cost-Benefit Analysis

Cost-Benefit Analysis is one of the important methods to evaluate the economic benefits of UAV technology. By comparing the differences between UAV and traditional methods in initial cost, maintenance cost and operating cost, the economic advantages of UAV technology can be intuitively seen. The figure below shows the cost comparison between UAV and traditional methods in these aspects. The data comes from an urban air quality monitoring project in New York City (see figure 3), which compares the performance of UAV and traditional monitoring methods in different cost categories. UAVs are significantly lower in initial cost and maintenance cost than traditional methods, and also have certain advantages in operating cost. This shows that UAV technology is not only more economical in terms of capital investment, but also reduces maintenance and operating costs in the long run, thereby improving overall economic benefits.

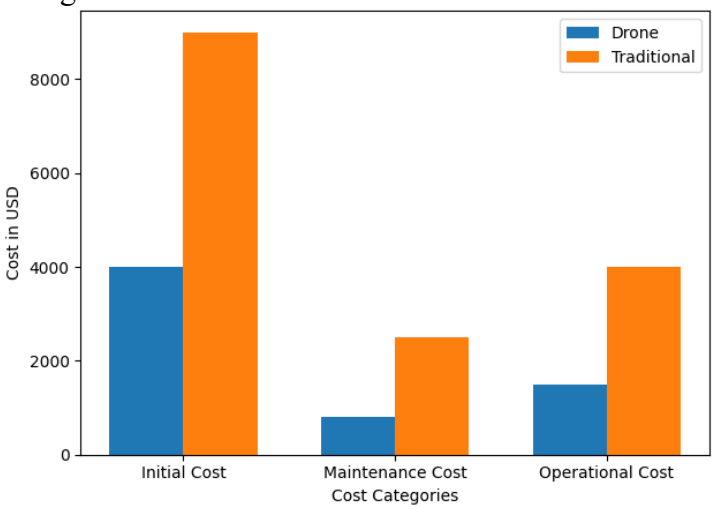

Figure 3: Cost Comparison between Drone and Traditional Methods

4.2 Economic Benefit Evaluation Methods

Economic benefit evaluation methods include cost-benefit analysis, return on investment (ROI) calculation, and net present value (NPV) analysis. Cost-benefit analysis evaluates the economic feasibility of different methods by comparing the total cost and total benefits. ROI calculation focuses on the ratio of the benefits of an investment project to its cost to evaluate the profitability of the project. NPV analysis evaluates the long-term economic benefits of a project by calculating the present value of future benefits. The following table shows the comparison between drones and traditional methods in terms of ROI and NPV. As shown in Table 1, drones outperform traditional methods in both indicators, indicating that they have higher economic benefits and investment value. These data are based on actual financial statements and revenue forecasts of a long-term urban environmental monitoring project implemented in San Francisco.

Table 1: Comparison of ROI and NPV between UAV and traditional methods

Method	ROI (%)	NPV (USD)
Drone	25	15000
Traditional	10	5000

4.3 Application Case Analysis

In urban environmental monitoring, there are many application cases of drone technology. A typical case is the application of drones in air quality monitoring. By carrying high-precision air pollution sensors, drones can monitor the concentration of pollutants in the air in real time and transmit data to the cloud for analysis and processing. Figure 4 shows the comparison between drones and traditional methods in terms of monitoring efficiency. As can be seen from the figure, drones are significantly better than traditional methods in terms of monitoring coverage and data processing speed, thereby greatly improving monitoring efficiency and data accuracy. The data comes from a project evaluation for urban air quality monitoring in Los Angeles.

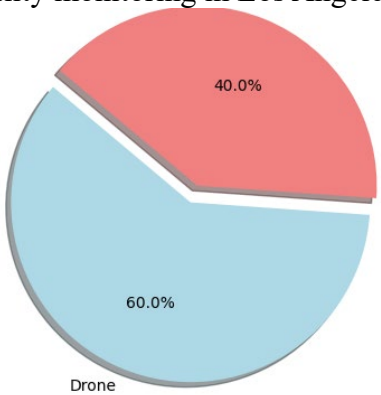

Figure 4: Efficiency Comparison between Drone and Traditional Methods

5. Conclusion

5.1 Main Conclusions

This paper studies the application of UAV technology in urban ecological environment monitoring and its economic benefit evaluation. Through a systematic discussion of the development overview, classification and specific application of UAV technology in environmental monitoring, this paper draws the following main conclusions:

First, UAV technology has significant advantages in environmental monitoring. Compared with the traditional ground monitoring point and satellite remote sensing, data obtained by UAVs have high temporal-spatial resolution, wide coverage, and strong flexibility. Multiple sensors mounted on the UAVs, including but not limited to high-definition cameras, infrared sensors, and lidar, enable efficient and accurate data acquisition of the environment, which greatly improves monitoring efficiency and accuracy.

Second, UAV technology also shows obvious advantages in cost-effectiveness. Through cost-effectiveness analysis of actual project data in New York City and San Francisco, UAVs are significantly lower than traditional methods in initial cost, maintenance cost and operating cost. In addition, UAVs are also superior to traditional methods in terms of return on investment and net present value, indicating that they have higher economic benefits and investment value.

Finally, UAV technology has shown a wide range of potential in practical applications. From air quality monitoring to water environment monitoring to disaster management, UAVs have played an important role. The urban air quality monitoring project in Los Angeles demonstrates the efficiency and accuracy of drones in data collection and processing, providing reliable technical support for environmental monitoring.

5.2 Research limitations

Although this paper has achieved some important conclusions in the application and economic benefit evaluation of drone technology, there are still some research limitations. First, the data sources are mainly concentrated in specific urban projects, such as New York City and San Francisco, and the sample range is relatively limited, which may not fully reflect the actual situation in different cities

and environmental conditions. Future research should expand the sample range to cover more regions and different environmental conditions to improve the generalizability of the research results.

Second, the application of drone technology in environmental monitoring still faces some technical and operational challenges. For example, the complexity of data processing and analysis, restrictive regulations on drone flights, and technical requirements for operators will affect the actual application effect of drones. Furthermore, the performance of drones in unfavourable weather conditions is also to be further verified.

Finally, there are certain limitations in the economic benefit evaluation method. Though this paper evaluates the economic benefits of drones considering indicators like cost-benefit analysis, return on investment, and net present value, these methods are mostly quantitative in nature and cannot measure qualitative aspects like environmental and social benefits. In future, more diverse evaluation techniques should be adopted to ascertain the overall benefits comprehensively.

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