Research on UAV Remote Sensing in River Monitoring

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Abstract. The scarcity and pollution of water resources pose significant constraints on both the economic development of a region and the well-being of its inhabitants. Effective monitoring of the water environment is crucial in addressing these issues. Currently, traditional methods for river water quality supervision, such as manual sampling and laboratory analysis, are inefficient and unable to provide real-time data. This paper explored the potential of Unmanned Aerial Vehicle (UAV) remote sensing technology in periodic monitoring of rivers, emergency monitoring of flood disasters, and monitoring of suspended sediment of water. The results show that: (1) UAV-carried sensors allow for the acquisition of high-resolution image data, enabling comprehensive monitoring of rivers throughout the entire cycle. This enhances our understanding of river dynamics and facilitates effective watershed management. (2) In terms of emergency disaster monitoring, UAVs offer rapid response and real-time data transmission capabilities. It provides timely information on riverine hazards, enabling quick response and mitigation measures. In addition, UAV-based monitoring is cost-effective and ensures the safety of operators. (3) UAV remote sensing can estimate and track the concentration of pollutants in rivers, enabling the assessment of pollution levels within watersheds. This information serves as a valuable resource for environmental protection efforts and the development of appropriate mitigation strategies.

Keywords: UAV, river monitoring, water environment, airborne remote sensing.

1. Introduction

In recent years, the protection and improvement of water resources in China have become crucial for promoting sustainable development and ecological construction. Water resources play a vital role in ensuring the security and stability of agricultural production. It is necessary to monitor the rivers in China.

Various traditional methods exist for monitoring river water quality, including manual field sampling, laboratory analysis, and station monitoring. But they all have obvious shortages. Site-based monitoring should normally be distributed to cover a wide range of areas and key locations in the target water body to ensure timely monitoring and effective assessment of changes in water quality. However, the distribution of monitoring sites in practice may suffer from inadequate monitoring coverage [1]. The monitoring of river water quality by artificial field sampling and laboratory analysis can only obtain the sampling point data of river cross-section, and the efficiency is low [2, 3]. Aerial remote sensing has emerged as an indispensable tool for monitoring river water quality. Aerial remote sensing is a technology that senses the electromagnetic radiation characteristics of feature targets by installing sensors on board aircraft and records these characteristics for identification and judgment. It can be widely used for water quality testing, generating massive amounts of data and providing rich content. Especially with the rapid development of UAV technology, the advantages of aerial remote sensing have gradually emerged. UAV remote sensing has the advantages of real-time data transmission, multiple detection types, and high resolution, which can be applied in many fields such as meteorology, environment, water conservancy, exploration, agriculture, and electricity [4]. Given the intricate geological and geomorphological features of China, water environment monitoring encounters diverse and complex environmental conditions, presenting substantial challenges. UAV remote sensing can ignore the influence of terrain and quickly obtain clearer images.

This paper investigates the application of UAV remote sensing monitoring technology in the periodic monitoring of rivers, emergency monitoring of flood disasters, and monitoring of suspended sediment of water. It also analyzes the advantages and shortcomings of UAV remote sensing technology in river monitoring.

2. UAV remote sensing technology

2.1. Overview of UAV remote sensing

UAV remote sensing is an emerging aerial remote sensing method that has developed alongside advancements in UAV. It utilizes UAVs as platforms equipped with various remote sensing sensors for data acquisition. UAV aerial remote sensing combines UAV flight technology, sensing technology, communication technology, GPS positioning technology, and other advanced technologies. By carrying different sensors, the UAV collects data and monitors targeted areas at low altitudes [5]. The selection of the appropriate UAV platform is essential to ensure effective data acquisition and operational flexibility. Different options for UAV platforms include rotorcraft, fixed-wing UAVs, and vertical take-off and landing UAVs (VTOL). Each platform has its unique advantages and application scenarios. Factors like flight stability, load capacity, flight duration, and environmental adaptability should be considered during selection [6]. Additionally, choosing the right sensor is critical to obtaining the type of data needed. Commonly used sensors include optical cameras, multispectral cameras, thermal infrared cameras, and laser radar (LiDAR). Each sensor provides different types of data, such as visible images, thermal images, vegetation indices, etc., thereby offering diverse information sources for subsequent data analysis [5].

2.2. Preprocessing of UAV images

2.2.1 Image distortion correction

Image deviation and lens distortion generated during UAV flight will affect data quality. Using professional image processing software to correct these distortions is an important step to ensure the accuracy of subsequent analysis. Image distortion correction methods include internal parameter correction and external element adjustment. These steps can improve the geometric accuracy of the image.

2.2.2 Aerial triangulation

Aerial triangulation is the core method of three-dimensional measurement and positioning based on image data. By analyzing the image data taken from different viewing angles and using the parallax principle to match the objects, the three-dimensional coordinates of the ground target are calculated accurately. This technique plays an important role in generating high-precision topographic maps and three-dimensional reconstruction.

2.2.3 Image fusion

UAV remote sensing image fusion technology allows for the integration of multi-temporal and multi-location image data, resulting in the generation of a perfect, high-resolution panoramic image. This technique not only provides a comprehensive and new perspective for monitoring areas but also significantly enhances the efficiency of data processing and the application value of the image.

3. UAV remote sensing for river monitoring

3.1. Periodic monitoring of rivers

Periodic monitoring of river basins is a complex yet crucial task, and the utilization of UAV technology is increasingly vital in this regard. By conducting basin-wide aerial photography operations using drones, high-resolution images of the river channel and its surrounding areas can be acquired, allowing for the generation of orthophoto maps encompassing the entirety of the basin. Through manual interpretation of these images, valuable information regarding the water environment can be obtained, providing a macroscopic understanding of the water conditions [8].

In a research study on river pollution levels in Suzhou City, the sample area was divided into two sections [9]. UAVs were used to acquire data in each section, as shown in Fig.1. To mitigate the impacts of atmospheric refraction and Earth curvature during image acquisition and ensure the acquisition of stable multispectral images of the study area, an optimal flight altitude of 200 meters and an airspeed of 5 m/s were set during data collection. To guarantee the correlation between remote sensing images and water sampling results, the acquisition of water sample data was synchronized with the acquisition of remote sensing image data, ensuring a time difference of no more than 2 hours. Ultimately, 39 sets of field sampling data were collected near the industrial sample area, while 51 sets were obtained near the residential sample area [7].

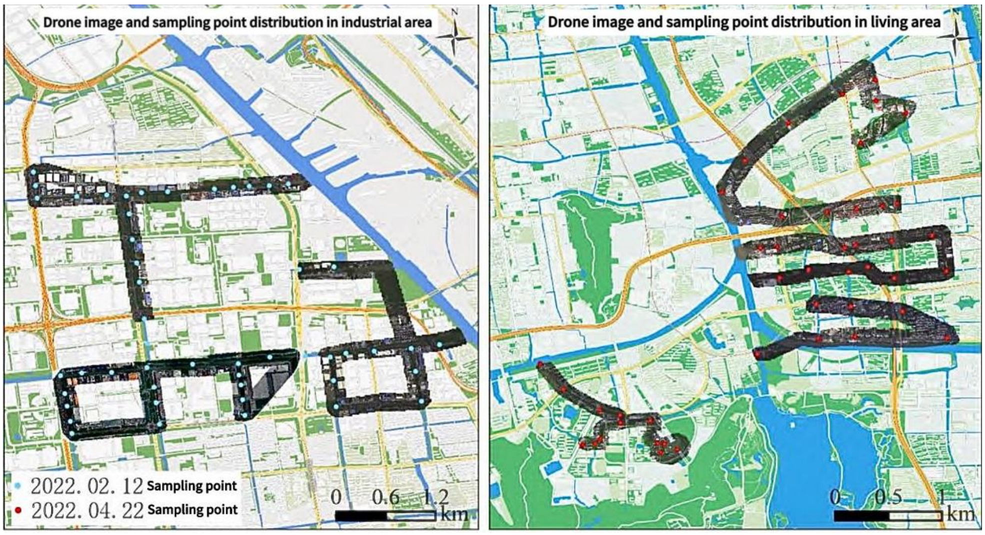

Figure 1. Sample points for data collection [7]

3.2. Emergency monitoring of flood disasters

In the event of a dangerous situation, UAV remote sensing technology can provide efficient support for emergency monitoring and rescue operations. UAVs can effectively monitor designated areas in real-time through remote sensing images, transmitting instant data to the ground to assist in ground dispatching. This technology plays a crucial role in safeguarding people's lives and protecting their property [6]. An example of the application of this technology occurred in June 2021, during severe flooding in the upper reaches of China's Heilongjiang River. The persistent heavy rainfall and the simultaneous rise of the Ergun and Shikha Rivers led to this disastrous event. Immediately after the calamity, the government organized aerial photographers to survey the affected areas. Different resolution shooting schemes were developed based on the specific conditions in each area. For instance, Huma County was divided into two blocks, Huma Embankment, and Huma County, with resolutions set at 4 cm and 8 cm, respectively. The Red Frontier Farm adopted a uniform resolution of 6 cm. Sanka Township was also divided into two blocks, Sanka Embankment, and Sanka Township, with resolutions of 4 cm and 6 cm, respectively. Details are provided in Table 1. When faced with disasters like floods, researchers can set an automated monitoring path to detect any leaks in flood control facilities. This approach enables them to promptly provide high-resolution remote sensing images of the affected areas. It effectively supports the inspection of critical flood control facilities, such as catastrophic dams, and facilitates timely response to potential leakage.

Table 1. Flightline parameters [8]

Area	Block	Resolution /cm	Course overlap /%	Side image overlap degree /%	Flight speed /(m/s)
Huma County	Huma Embankment	4	80	60	13.5
	Huma County	8	80	58	13.5
Red Frontier Farm	The whole area	6	80	60	13.5
Sanka Township	Sanka Embankment	4	80	60	13.5
	Sanka Township	6	80	60	13.5

3.3. Analysis of results of UAV monitoring of river

UAVs can obtain high-resolution images quickly and flexibly. Researchers can control flight parameters according to the field conditions in the study area to obtain high-quality images. In addition, the image data acquisition efficiency is high and the monitoring coverage can be wide. In traditional water quality monitoring, the requirements are evenly distributed and reasonable. Sometimes the sampling points need to be distributed in different areas according to the density of population near the watershed or the vegetation coverage of the surrounding area. At this time, UAV remote sensing is favored because it can determine the coverage of remote sensing images at will.
Traditional methods of flood disaster monitoring are limited by factors such as manpower, material resources, and time, and cannot meet the needs of emergency monitoring. The UAV can quickly reach the area that needs to be monitored and flexibly conduct monitoring over the river. And it is not limited by terrain and geographical conditions. The high-resolution cameras or sensors carried by UAVs can obtain high-quality, high-resolution image data, which can provide detailed topographic, hydrological, ecological, and other information, helping to accurately identify problems or emergencies in rivers. The use of drones for monitoring can reduce the risk of personnel in dangerous environments and improve the safety of the work.

4. Monitoring of suspended sediment of water

Suspended sediment is one of the important indicators of water quality, which is of great significance for water resources management, river ecosystem protection, and soil erosion. This paper takes the waters of the Pearl River Estuary as an example to sample the study area, as shown in Fig. 2. The data acquisition and data processing of UAV remote sensing are analyzed, and the method and application of the inversion model of suspended sediment mass concentration are introduced.

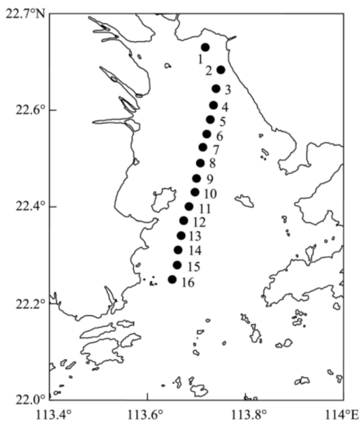

Figure 2. Study area and the distribution of sampling points [9]

4.1. Analysis of sediment-sensitive bands

It is necessary to find out the bands sensitive to suspended sediment before monitoring the concentration of suspended sediment. We need to analyze the correlation coefficients between suspended sediment mass concentration and remote sensing reflectivity in different bands. As can be seen from Fig. 3, the correlation coefficient in the Blue band is relatively low. The correlation coefficient near the first reflection peak (580 nm) is only 0.33, which indicates that this band is strongly influenced by other water quality parameters (e.g., chlorophyll, yellow matter) in addition to suspended sediment. Therefore, the inversion of suspended sediment using the Blue band may introduce a large error. The correlation coefficient increases significantly when the wavelength increases, with the maximum value occurring near 742 nm. In the wavelength range greater than 750 nm, the changes in this part of the reflectance spectrum are mainly due to the scattering effect of the suspended sediment due to the strong absorption of the water column [9]. Therefore, the band at 742 nm was chosen as a sensitive band for suspended sediment.

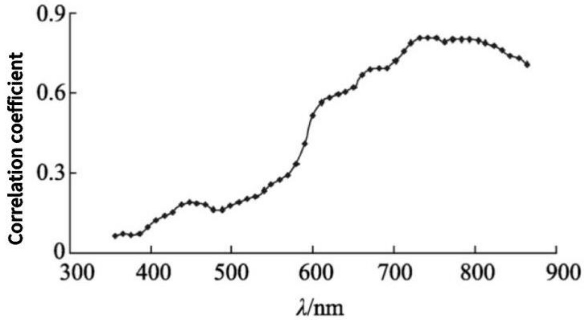

Figure 3. Correlation between suspended sediment concentration and remote sensing reflectance [9]

4.2. Inversion of suspended sediment concentration in water

The ratio of remotely sensed reflectance between different bands is commonly utilized to estimate the concentration of suspended sediment. In our previous analysis, we determined that the 742 nm band exhibited the highest correlation with suspended sediment mass concentration. Therefore, we selected this band as a potential candidate for modeling purposes. By calculating the ratio of the remotely sensed reflectance in this band to other bands, we established regression equations between the ratio and the suspended sediment mass concentration using the least squares method. Subsequently, we calculated the root-mean-square error between the predicted values of suspended sediment mass concentration obtained from each regression equation and the corresponding measured values. The results are depicted in Fig. 4. From Fig. 4, it can be seen that the RMSE between the inversion value and the measured value of the suspended sediment mass concentration of the fitting equation with a center wavelength of 742 nm is the largest. The RMSE between the inverse value and the measured value of the suspended sediment mass concentration of the ratio fitting equation with the center wavelength of 548.92 nm is the smallest. Hence, we select the 548.92 nm band. Consequently, we establish the regression equation for suspended sediment mass concentration using the ratio of the 742 nm band to the 548.92 nm band. We employ linear, exponential, power function, and logarithmic functions for regression fitting, and the corresponding calculation results are presented in Table 2. As observed from Table 2, the linear fit yields the strongest correlation among the regression models [9].

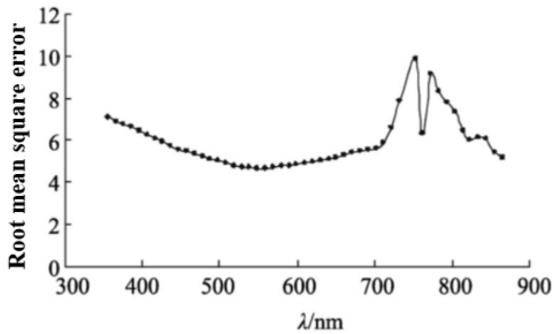

Figure 4. Root mean square errors for retrieved and measured suspended sediment concentrations at different and remote sensing reflectance [9]

Table 2. Fitted regression equations for suspended sediment concentration

Fitting method	Formula	R^2
Exponential fit	$y=6.23e^{6.13x}$	0.77
Power function fit	$y=175.87x^{1.9}$	0.78
Logarithmic fit	y=37.3lnx+66.37	0.77
Linear fit	y=123.85x-17.24	0.80

4.3. Inversion results of suspended sediment mass concentration

Fig. 5 shows the spectral curves of suspended sediment with different mass concentrations. As can be seen from Fig. 5, with the increase of suspended sediment mass concentration, the remote sensing reflectance of the spectral spectrum of the sand-containing water increases significantly in the visible range, and a reflection peak is formed around 580 nm and 810 nm, respectively. At 580 nm, the reflectance curve can distinguish between different suspended sediment concentrations. The ratio of suspended sediment mass concentration to the remote sensing reflectance band of sand-bearing water increases significantly with the increase of wavelength and reaches the maximum value near 742 nm [9].

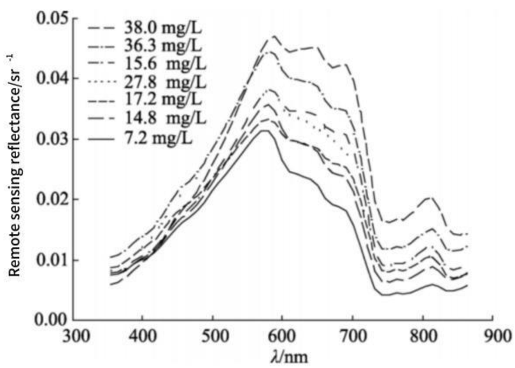

Figure 5. Reflectance curve of suspended sediment with different mass concentration in different bands [9]

5. Summary

In this paper, the application of UAV remote sensing in river monitoring is reviewed. Including UAV remote sensing data acquisition for image analysis and processing, the application of UAV remote sensing in periodic monitoring of rivers, emergency monitoring of flood disasters, and monitoring of suspended sediment of water re-discussed. The high-resolution sensor carried by the UAV in the whole-cycle monitoring of the river can obtain high-quality and high-resolution image data. It provides detailed terrain, hydrology, ecological, and other information, which is conducive to the whole-cycle systematic monitoring of the river. In flood emergency monitoring, UAV has the advantage of rapid response and is not limited by terrain and geographical conditions. Real-time data transmission and timely understanding of river disasters are essential for the timely discovery of emergencies and emergency response. In addition, UAV monitoring can reduce the risk of personnel in dangerous environments and improve work safety. In the study of water pollution monitoring, UAV remote sensing can invert the concentration of river pollutants, and then infer the pollution situation in the basin. The use of UAVs in monitoring river basins is crucial for protecting the ecological environment of the river and promoting the rational use of water resources.

Authors Contribution

All the authors contributed equally and their names were listed in alphabetical order.

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