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Exploring the Impact of Drone Remote Sensing Technology on Rice Productivity

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Abstract:

Unmanned Aerial Vehicle (UAV) remote sensing technology offers new solutions to many of these problems in traditional agricultural management. This paper delves into the application of UAV remote sensing technology in rice production, exploring how this advanced technology significantly enhances the efficiency of rice production. Continuous, real-time data provided by UAV remote sensing at different rice growth stages are crucial for agricultural producers. They allow for timely adjustments in management strategies, thereby maximizing rice production efficiency. This paper points out that UAV remote sensing can not only effectively monitor rice pests and diseases, accurately estimate yield, and optimize the use of nitrogen fertilizer by analyzing the spectral reflectance of the rice canopy. Furthermore, this paper emphasizes the application value of UAV remote sensing technology in monitoring the Leaf Area Index (LAI) of rice, which not only helps in precise water and fertilizer management, reducing production costs, but also provides a scientific basis for agricultural production decisions, improves the accuracy of yield forecasts, and promptly detects pests and diseases, enhancing the disease resistance of rice. Future research needs to continuously explore and innovate to overcome these challenges, enabling UAV remote sensing technology to play a greater role in promoting sustainable agricultural development, ensuring food security, and protecting the ecological environment.

Keywords: Remote sensing; UAV; Rice.

1. Introduction

As China‘s number one grain crop, rice is planted in an area of about 0.3 billion hm2, and the stable and high rice yield is crucial for national food security [1]. However, rice is susceptible to pests, diseases, soil conditions, and other factors during its growth. Scientific field management has become an essential guarantee for rice‘s stable and high yield. Influenced by natural conditions, agricultural development status, and urbanization, traditional planting range delineation and growth observation rely on field surveys with low timeliness and accuracy. With its advantages of high spatial and temporal resolution, flexibility, and cost-effectiveness, the UAV remote sensing technology provides a unique means of data collection for rice production management, significantly reducing the working time and human and material resources while meeting the sampling accuracy requirements.

UAV remote sensing is an uncrewed aerial vehicle as a carrier, carrying a variety of remote sensing sensors, such as cameras, spectral imagers, LIDAR scanners, and other remote sensing sensors to obtain high-resolution optical images, videos, LIDAR point clouds, and other data [2]. Compared with the traditional satellite-based platform of space remote sensing, UAV remote sensing can fly at low altitudes under the clouds, which makes up for the defects of satellite optical remote sensing that are often blocked by clouds to obtain images. In rice production, UAV remote sensing technology has been widely used in many aspects, such as crop monitoring, pest and disease identification, irrigation management, etc., providing new tools and methods to ensure efficient rice production. For example, OGAWA et al. designed a deep learning method that can utilize UAV visible light cameras to be able to accurately identify rice spike positions in paddy fields, assisting in the selection and breeding of rice varieties [3]. DAISUKE et al. combined UAV low-altitude remote sensing data to obtain rice coverage and established a model relationship between UAV remote sensing images, rice biomass, and quantitative trait loci [4].

This paper explores the typical application of UAV remote sensing technology in rice. Its practical impact on production efficiency is specifically analyzed. Subsequently, it elaborates on the opportunities and challenges the research faces in deploying UAV remote sensing technology in rice production. By comparing the research progress in related fields at home and abroad, the potential application prospects of UAV remote sensing in enhancing rice production efficiency are prospected. The research in this paper can provide technical references for the related work of UAV remote sensing technology in rice production.

2. Overview of the UAV Remote Sensing Platform

The UAV remote sensing platform is necessary for conducting quantitative remote sensing research on rice. The equipment mainly consists of the UAV flight platform and the remote sensing payload. Different flight platforms correspond to different rice production scales, and the remote sensing payload mainly determines the type of rice remote sensing data to be acquired.

2.1 Main UAV Flight Platforms and Their Common Payloads

More electric UAV platforms are currently used in agricultural UAV remote sensing research and applications. According to its wings and different flight methods, UAV flight platforms can be categorized into multi-rotor, fixed-wing, and composite flight platforms. The commonly used flight platforms in the rice UAV remote sensing field and their advantages and disadvantages are shown in Table 1.

Multi-rotors can hover in the air, facilitating filming and monitoring missions, but have poor range. Fixed wings have the advantage of high endurance and are suitable for long-duration monitoring and reconnaissance missions, but they are less maneuverable. Composite flying platforms combine the advantages of multi-rotors and fixed wings, but they are more expensive due to their complex structure.

Table 1. Commonly used flight platforms for quantitative remote sensing of rice

Category	Model	Applicable scenario	Advantages	disadvantages
Multi-rotor	Dji/Genie series	$\leq 20hm^2$	Good mobility and easy handling	Poor range
Multi-rotor	Dji/Warp series	$\leq 40hm^2$		
Fixed-wing	Ebee/RTK series	$\leq 70hm^2$	Great endurance and speed	Less mobility
Fixed-wing	Three Airlines/MTD100	$\geq 70hm^2$		
Composite-wing	Feima/v1000	$\geq 70hm^2$	Good mobility and range	high cost

Remote sensing payload is the main instrumentation carried to the UAV flight platform to acquire remote sensing information of rice, which mainly includes digital camera, multispectral camera, hyperspectral imager, thermal imager, LIDAR, sunlight-induced chlorophyll fluorimeter, etc., according to the type of data acquisition. In practical applications, different remote sensing payloads are selected according to the data type acquired. Among them, a multispectral camera is a remote sensing image acquisition device composed of specific wavelengths. It is mainly used for monitoring rice pests and diseases and estimating yields; the hyperspectral imager, whose main wavelength range is 400~1000 nm, is mainly used to convert rice nitrogen and other elements.

2.2 Rice UAV Remote Sensing Data Processing

The UAV flight platform and remote sensing payload are the hardware basis for quantitative remote sensing by rice UAVs. In contrast, the acquisition of high-quality remote sensing data from rice field UAVs for quantitative analysis requires the support of software. At present, UAV flight platforms are equipped with autonomous flight control software, which can ensure that remote sensing data are collected following standardized routes in the area to be analyzed. After obtaining the raw data of remote sensing images, it is usually necessary to stitch the remote sensing images. Then, it is necessary to carry out a series of remote sensing image pre-processing, including geometric correction, radiometric calibration, cropping, etc. The pre-processed remote sensing images can be modeled by extracting the region of interest for remote sensing inversion. After that, it is often necessary to visualize the remote sensing results for further analysis.

3. Application of Unmanned Aerial Remote Sensing in Monitoring Rice Productivity

In rice production, many factors can lead to the decline of rice productivity. Among them, pests and diseases are the main disasters in rice production, and according to statistics, the global loss of rice production due to pests and diseases reached 30% in 2019 [5]. In the process of rice production, pests, and diseases need to be found in time and accurately identified in order to ensure the planting yield of rice and improve the efficiency of rice production. At the same time, the accurate estimation of rice yield is of great significance in rice production, which can effectively support the balance of food supply and demand, agricultural policy making, etc., and further improve rice productivity. With the continuous development of UAV remote sensing technology, many scholars have begun to study the method of monitoring rice productivity using this technology's mobility and flexibility.

3.1 Monitoring of Rice Pests and Diseases Using Drone Remote Sensing

Qin Z H et al. from the Chinese Academy of Agricultural Sciences (CAAS) used UAV airborne hyperspectral data to analyze rice's spectral characteristics under the stripe blight stress. Visible and near-infrared spectra can be used to detect rice stripe limp, and a series of spectral indices were proposed to predict the degree of development of rice pests and diseases[6]. However, due to the similarity and overlapping parts of the spectra between healthy rice plants and diseased plants, it is difficult to distinguish between the spectra of slightly diseased plants and healthy plants when the disease is of a mild degree.AN et al. used multi-temporal hyperspectral data from an unmanned aerial vehicle. They used the method of spectral and temporal feature coupling to establish a rice stunt disease detection model with an identification accuracy of 85% [7]. Xiao Wen et al. used the split-window Gram-Schmidt variation to extract features from UAV hyperspectral remote sensing images of rice fields. They used the PSO-SVR algorithm to establish a rice blast disease index detection model [8]. Kong Fanchang et al. used a UAV hyperspectral platform to obtain rice spikelet blight canopy data of different disease classes, used random forests to establish an identification model, and combined with rice physiological parameters to explain the characteristic associations of the inputs. The prediction set accuracy reached 90%, which was capable of explaining the process of comprehensive changes in the overall physiological parameters of the plant caused by spikelet blight [9].

3.2 Estimating Rice Yields Using Drone Remote Sensing

The commonly used UAV remote sensing method for yield estimation is to establish a statistical model between vegetation indices and yields at multiple fertility periods. It is widely used due to its advantages of simplicity and efficiency. However, the natural conditions of the spectral information obtained at different time points are bound to be different, and the extracted vegetation indexes are bound to have certain errors, affecting yield estimation accuracy. Studies have used the concepts of „relative spectral variables“ and „relative yield“ to carry out multi-temporal UAV remote sensing estimation of rice yield, and the average relative error is less than 5% [10]. DUAN et al. used UAV remote sensing technology to study rice under different climatic conditions and effectively inverted the rice yield by the multi-temporal inversion method. The error accuracy was within 7% [11]. Tian Ting et al. established a fitting relationship between eight vegetation indices extracted from different fertility periods and the measured values of rice yield, screened out the optimal vegetation indices and the optimal period of UAV remote sensing operation, and established a model for rice yield estimation, which further improved the effect of rice yield estimation [12]. In addition to the use of vegetation index for yield monitoring, some researchers have also used the fusion of hyperspectral information and texture features to construct a UAV remote sensing yield estimation model for rice breeding plots, which improves the accuracy of the traditional machine learning methods for estimating rice yield [13].

4. Analysis of Nitrogen Content of Rice Canopy Based on Spectral Reflectance Results

Nitrogen is an important component in forming biomolecules such as amino acids, nucleic acids, and proteins. During rice growth, nitrogen is involved in the formation of chlorophyll, cell walls, and other key molecules that contribute to the overall growth of rice. Rice canopy spectral reflectance is significantly and positively correlated with leaf nitrogen content, and metrics such as Normalized Difference Vegetation Index (NDVI), Green Band Normalized Vegetation Index (GNVI), and Ratio Vegetation Index (RVI) have been widely used to estimate the nitrogen content of rice leaves [14]. In the process of agricultural production, the application of inorganic nitrogen fertilizer is the basis for improving crop yield. Still, the excessive application of nitrogen fertilizer will have adverse effects on the ecosystem and plant development. Therefore, improving crop nitrogen utilization efficiency is the key to the sustainable development of agriculture [15]. With the development of remote sensing technology, satellite-based spectroscopy has been used as a method of nitrogen diagnosis in many fields, such as agriculture [16-17].

The experiment of Pei Xinbiao and others used a six-axis twelve-rotor UAV with a spectrometer to form an agricultural remote sensing system to test the changing law of the spectral index of rice with different nitrogen application levels. It concluded that it is feasible to use a UAV with a spectrometer to form an agricultural remote sensing system to obtain the vegetation index through inversion.

The experiment showed that in the wavelength range of 380-750 nm (visible light), the overall reflectance was smaller than that in the infrared light range with wavelengths greater than 750 nm because the higher the nitrogen level, the higher the chlorophyll content, which led to an increase in the overall reflectance. In the infrared range, the reflectance N3 > N4 means that higher nitrogen will negatively affect chlorophyll accumulation above a certain nitrogen level.

Ling Qi-Han et al. [18] set up field experiments with different nitrogen levels in Mengzha Town, Xishuangbanna, Yunnan Province, and Beibei District, Chongqing Municipality, respectively, and utilized the DJI Elf 4 multispectral drone to collect multispectral images of the rice canopy at the tillering, nodulation, and tasseling phases of the rice, and used the Kjeldahl nitrogen determination method to determine the nitrogen content of the canopy of the rice plant. This experiment optimized the related shortcomings of a portable ground spectrometer with a small monitoring range and large workload, which made it difficult to realize field-scale crop nutrition monitoring and agricultural inversion.

Luo Zhengzong et al. explored the nitrogen allocation of rice plants at various fertility periods and the performance of nitrogen use efficiency and its constitutive factors through different nitrogen fertilizer application rates. The results showed that the total nitrogen content of rice plants increased with the increase of nitrogen fertilizer application. The increase of nitrogen fertilizer application relatively increased the total nitrogen uptake of plants, and the total dry matter weight also increased.

5. Application of UAV Remote Sensing Technology in Rice Growth Monitoring

Leaf area index (LAI) is one of the main crop growth parameters currently monitored by Unmanned Aerial Vehicle (UAV) remote sensing, and it is very important for crop growth, photosynthesis, and final crop yield[19]. LAI specifically refers to the total area of one-sided leaf blades per unit land area. It is closely related to various biochemical parameters of the crop, including pigment content, carbon cycle, biomass, and phenology, making it an important parameter for characterizing crop growth conditions and predicting crop biomass[20]. Monitoring rice LAI can effectively guide the rational application of fertilizers, regulate canopy structure, and predict and enhance yields[21]. Therefore, the rapid, non-destructive, and accurate acquisition of crop LAI is of great importance for assessing the growth vigor of rice, estimating final growth outcomes, and improving the efficiency of rice agricultural production[22].

Traditional methods of acquiring crop LAI data generally involve manual sampling and direct measurements, such as the specific leaf weight method and measurements with optical instruments. Although these methods can accurately obtain data, they are time-consuming, labor-intensive, have poor timeliness, and have low efficiency, making it challenging to quickly acquire LAI data over large areas[23].In contrast, UAVs offer several advantages, including lightweight, compact size, high performance, low cost, and ease of operation. Monitoring crop growth with UAV remote sensing technology can save labor and resources[24]. Moreover, low-altitude UAV remote sensing can utilize a variety of optical sensors, enabling the extensive use of data-driven, physical model-driven, and data assimilation methods to invert LAI at the scale of rice fields[22].

Remote sensing has become an effective technical tool for estimating LAI, also known as „inversion," due to its cost-effectiveness, efficiency, and non-destructive advantages. There are generally two methods for LAI inversion; the one we use involves obtaining remote sensing images of the study area with sensors mounted on UAV, followed by modeling plant LAI through empirical statistical models using vegetation indices. Sensory devices include digital, multispectral, hyperspectral, and thermal infrared cameras, among others. In particular, digital cameras are one of the most widely used sensors in UAV remote sensing. Compared to hyperspectral and multispectral cameras, they offer a number of advantages, such as lower cost of data acquisition, ease of use, and higher spatial resolution of the images[23].

In the experiments by Cao Zhongsheng et al. [23], remote sensing images were obtained using digital camera sensors mounted on UAVs and combined with mathematical models to calculate LAI accurately. The experimental setting was in Jiebu Town, Xingan County, Jiangxi Province, focusing on early rice fields of different varieties and nitrogen application rates. During the experiment, the digital camera sensors were set to the autofocus and auto exposure modes. Once the digital images were captured, Agisoft Photoscan Professional software was used to stitch them. This resulted in digital orthoimages of the entire rice trial field. In sync with the UAV digital image acquisition, four representative rice plants with uniform growth from each plot were returned to the laboratory. The sample plants were separated into leaves, stem sheaths, and panicles based on the developmental state of the plant organs. A specific mathematical model calculated The LAI within the specified area.

6. Conclusion

This article mainly analyzes the application of UAV remote sensing technology in rice production. Throughout the rice growth cycle, UAV remote sensing technology can provide continuous, real-time data, assisting agricultural producers in timely adjusting management strategies to maximize rice production efficiency. Additionally, UAV remote sensing can effectively monitor rice pests and diseases and accurately estimate yields. It has been observed from the spectral reflectance of the rice canopy that an excessive accumulation of nitrogen beyond a certain threshold can negatively affect chlorophyll accumulation in practical fertilization scenarios. Therefore, it is necessary to determine the amount of fertilization based on various factors, including soil texture, the needs during the rice growth period, and the type of nitrogen fertilizer, to implement scientific fertilization management and ensure the healthy growth and maximum yield of rice. Moreover, precise monitoring of rice‘s LAI can help farmers manage water and fertilizers more efficiently and reduce costs, providing a scientific basis for agricultural production decisions, improving and accurately predicting yields, and promptly detecting pests and diseases to enhance rice‘s disease resistance. Additionally, comparing the LAI of different varieties can provide references for rice variety improvement, further enhancing rice production efficiency.

Although some significant achievements of UAV remote sensing technology in rice production are notable, it still faces several challenges and issues that require further optimization and innovation. The practical application of UAV remote sensing technology has its limitations, especially in guiding field fertilization and pesticide application, which are still relatively underdeveloped; the application of UAV remote sensing is easily affected by external factors such as weather, sunlight, and wind speed, necessitating the adoption of new technological measures to minimize these impacts. In summary, although the impact of UAV remote sensing technology on rice production efficiency has been widely recognized, continuous innovation and development are still needed to allow UAV remote sensing to make greater contributions to achieving sustainable agricultural development, food security, and environmental protection.

Authors Contribution

All the authors contributed equally, and their names were listed alphabetically.

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