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# Research on Beyond Visual Range Intelligent Spraying Detection Unmanned Aerial Vehicles

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***ABSTRACT:*** *Rice, being an important grain crop in China, its pest and disease control holds critical significance for safeguarding grain yield and quality. With the rapid development of science and technology, unmanned aerial vehicle (UAV) technology has been gradually adopted in the domain of rice pest and disease detection, bringing about novel changes to traditional agriculture. This article centers on the application of UAVs in rice pest and disease detection, elaborating in detail their advantages, key technologies, as well as the challenges and coping strategies. Through a large number of field experiments and data analyses, it is discovered that UAVs outfitted with high-resolution cameras, multispectral sensors, and other equipment can acquire images and data information of rice fields rapidly and precisely. Utilizing advanced image processing techniques and machine learning algorithms, it is feasible to effectively identify the characteristics such as disease spots and pest traces on rice leaves, and accurately determine the types and severity of pest and diseases. This research not only summarizes the latest advancements of UAV technology in rice pest and disease detection but also conducts an in-depth analysis of its advantages and challenges in practical applications, offering valuable references and inspirations for researchers and practitioners in relevant fields.*

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## I. RESEARCH BACKGROUND

Rice, as a globally vital food crop, is subject to numerous pest and disease incursions during its growth process[1]. Traditional approaches for detecting rice pests and diseases predominantly rely on manual field inspections and statistics[2]. Such methods are not only time-consuming and laborious but also inefficient, making it arduous to achieve large-scale and real-time monitoring. With the rapid advancement of technology, unmanned aerial vehicle (UAV) technology has gradually come to the fore, offering novel technical means for rice pest and disease detection.

In recent years, the application of UAV technology in the agricultural domain has become increasingly extensive[3], and its advantages in rice pest and disease detection have gradually come to light. UAVs, when outfitted with advanced sensors and imaging equipment, can acquire images and data information of large-scale rice fields rapidly and efficiently. Through image processing techniques and machine learning algorithms, features such as disease spots and pest traces on rice leaves can be precisely identified, thereby determining the types and severity of pests and diseases. The advent of this technology has significantly enhanced the efficiency and accuracy of rice pest and disease detection, bringing convenience to agricultural production.

Nevertheless, the application of UAVs in rice pest and disease detection still confronts several challenges[4]. For instance, complex field environments might affect the quality of images, resulting in misjudgments and omissions. Additionally, the endurance and data processing capabilities of UAVs require further enhancement to meet the requirements of large-scale farmland detection. Hence, in-depth studies on the application of UAVs in rice pest and disease detection hold considerable significance for promoting agricultural modernization and safeguarding national food security[5].

## II. RESEARCH OBJECTIVES AND SIGNIFICANCE

Enhancing Detection Efficiency: Employing unmanned aerial vehicle (UAV) technology to acquire images and data information of large-scale rice fields rapidly and efficiently, enabling real-time monitoring and enhancing the efficiency of pest and disease detection[6].

Enhancing Accuracy: Through image processing techniques and machine learning algorithms, accurately identify features such as disease spots and pest traces on rice leaves, reducing misjudgments and omissions, and improving the accuracy of pest and disease detection.

Optimizing Control Strategies: Based on the types and severity of pests and diseases detected by

UAVs, formulate targeted control strategies to enhance control efficacy and reduce pesticide utilization.

Promoting Agricultural Intelligence: Integrating UAV technology with agricultural Internet of Things, big data, and other technologies to advance the development of agricultural intelligence and elevate the intelligence level of agricultural production.

Reducing the Burden on Farmers: The research and development of this UAV can minimize a considerable amount of onerous manual labor, utilize technology to assist farmers in making scientific decisions, and avoid losses resulting from incomplete understanding.

Ensuring Food Security: Rice is one of the significant food crops in China, and its output and quality are directly related to national food security[7]. Utilizing UAV technology for pest and disease detection can promptly discover and control the occurrence and dissemination of pests and diseases, guaranteeing rice yield and quality, and thereby maintaining national food security.

Driving Income Growth for Relevant Personnel: Through precise pest and disease detection and control strategies, rice yield and quality can be enhanced, increasing farmers' income and promoting rural economic development. Additionally, it creates new employment positions in technology research and development, sales, after-sales services, and drives the development of related industries.

Promoting Sustainable Development: UAVs can precisely apply fertilizers and pesticides in agricultural production, reducing the consumption of chemical fertilizers and pesticides, lowering pollution to soil, water sources, and the air, and contributing to ecological protection and sustainable agricultural development, aligning with the global pursuit of green and environmentally friendly agriculture.

## III. THE APPLICATION OF UNMANNED AERIAL VEHICLE (UAV) TECHNOLOGY IN AGRICULTURE

With the rapid advancement of technology, unmanned aerial vehicle (UAV) technology, with its distinctive advantages, is being increasingly and profoundly applied in the agricultural domain, gradually emerging as a crucial force propelling the modernization process of agriculture[8]. As an efficient, flexible, and powerful aerial platform, UAVs can be equipped with a variety of advanced sensors and apparatuses, offering unprecedented convenience and precision for the monitoring and management of farmlands.

In the critical aspect of monitoring rice pests and diseases, the application of UAVs has manifested tremendous potential and advantages[9]. Traditional methods for pest and disease monitoring typically rely on manual inspections or fixed ground monitoring stations. These approaches are not only time-consuming and labor-intensive but also difficult to achieve large-scale and real-time monitoring, often resulting in belated detection of pests and diseases and the loss of the optimal control opportunity. In contrast, UAVs, with their high-altitude perspectives and flexible flight capabilities, can effortlessly cover vast areas of rice fields, enabling rapid and efficient monitoring[10].

Specifically, UAVs can be outfitted with high-resolution cameras that can capture every minute change in rice plants, including the color, shape, and texture of leaves. Through image processing techniques, these images can be transformed into valuable data for analyzing the occurrence of pests and diseases. For instance, when rice plants are assaulted by pests and diseases, their leaves often exhibit obvious symptoms such as color alterations, spots, and wilting. Image processing algorithms can automatically identify these symptoms and precisely determine the type and severity of pests and diseases.

Furthermore, UAVs can also be equipped with advanced devices such as multispectral cameras to further enhance the accuracy of pest and disease identification. Multispectral cameras can concurrently acquire image information in multiple bands, including visible light and near-infrared, providing data support on various aspects such as the growth status, chlorophyll content, and water condition of rice plants. Through comprehensive analysis of these data, it becomes possible to more accurately ascertain whether rice plants are affected by pests and diseases, as well as the specific type and severity of the pests and diseases. This multi-dimensional information acquisition and analysis capability is beyond the capacity of traditional monitoring methods.

## IV. PRINCIPLES AND METHODS OF PEST AND DISEASE DETECTION

### 4.1 Analysis of Characteristics of Rice Pests and Diseases

The characteristic analysis of rice pests and diseases constitutes an essential basis for rice health management and pest and disease prevention and control. Through in-depth analyses of the appearance, physiological, and spectral characteristics of rice pests and diseases, we can determine the types of pests and diseases and their influence on rice growth more precisely. Different types of pests and diseases will exhibit their distinct symptoms in various parts of the rice plant, such as leaves, stems, and panicles. These symptoms encompass but are not limited to spots, yellowing, leaf curling, wormholes, and moldiness. For instance, rice blast often leads to grayish-white to brownish disease spots on leaves, while the damage caused by rice planthoppers might induce leaf yellowing and stunted growth. By meticulously observing and documenting these appearance characteristics, in combination with the occurrence patterns of pests and diseases and meteorological conditions, we can preliminarily determine the types of pests and diseases, providing a basis for further diagnosis and prevention and control.

Pests and diseases not only impact the appearance of rice but also modify its physiological indicators. Changes in physiological parameters like chlorophyll content, photosynthetic rate, water content, and respiration can reflect the degree of the impact of pests and diseases on rice. Utilizing various sensors, such as chlorophyll meters, photosynthesis meters, and soil moisture meters, we can monitor the changes in these physiological characteristics in real time. This monitoring approach based on physiological indicators can detect abnormalities in the early stage of pests and diseases, facilitating the adoption of timely prevention and control measures and reducing losses.

Pests and diseases also exert an influence on the spectral reflection characteristics of rice. In different spectral bands, rice affected by pests and diseases will display unique spectral features. Through the application of multispectral cameras or hyperspectral imaging technology, we can obtain spectral images of rice in different bands. Analyzing these spectral images can reveal the impact of pests and diseases on the spectral reflection characteristics of rice, thereby achieving accurate identification of pests and diseases. This method possesses the advantages of non-contact, rapidity, and accuracy, providing a novel means for the monitoring of rice pests and diseases.

### 4.2 Image processing and analysis methods

Image processing and analysis constitute the crucial links in the monitoring of rice pests and diseases by unmanned aerial vehicles (UAVs). Through the preprocessing, feature extraction, and target recognition and classification of the collected images, valuable information can be extracted from a vast amount of image data, providing a scientific basis for the monitoring and control of pests and diseases.

Owing to the influence of multiple factors during the flight of UAVs, such as lighting conditions, air currents, and shooting angles, the collected images frequently exhibit issues like noise, color deviation, and insufficient contrast. Hence, prior to image analysis, it is imperative to preprocess the images to enhance their quality and clarity. Image preprocessing encompasses operations such as denoising, white balance adjustment, and image enhancement. Denoising can reduce random noise in the image and enhance its smoothness; white balance adjustment can rectify color deviations in the image and make it represent the actual color of rice more accurately; image enhancement can augment the contrast and detail information of the image, rendering it more distinct and recognizable.

The preprocessed images contain abundant information, yet not all of it pertains to pests and diseases. Consequently, it is necessary to extract features related to pests and diseases from the images. Commonly employed feature extraction methods include color features, texture features, and shape features. Color features can be obtained by analyzing the RGB or HSV color space of the image; texture features can be described by computing the gray-level co-occurrence matrix, local binary patterns, etc.; shape features can be acquired through edge detection and contour extraction. These features can reflect the growth status of rice and the circumstances of pests and diseases, providing a foundation for subsequent target recognition and classification.

After extracting the features of the images, machine learning algorithms are utilized for the training and classification of the features. Frequent machine learning algorithms encompass support vector machines (SVM), neural networks, random forests, etc. By applying these algorithms to the training dataset, the mapping relationship between different features and types of pests and diseases can be learned. Subsequently, applying this trained model to new image data enables the automatic recognition and classification of pests and diseases. This approach boasts the advantages of high efficiency and accuracy, which can significantly improve the efficiency and accuracy of pest and disease monitoring.

## V. EXPERIMENTAL DESIGN AND DATA COLLECTION

### 5.1 Data collection

Regarding rice leaf pests and diseases, no public datasets are available currently. This study constructed a dataset using the pests and diseases captured in real outdoor rice fields. The types of pests and diseases encompassed are: healthy (Normal), blight (Blight), brown spot (Brown Spot), dead heart (Dead Heart), downy mildew (Downy), false smut (False), blast (Blasst), sheath blight (Sheath Blight), streak (Streak), and tungro (Tungro), totaling ten kinds. The image capturing device was Xiaomi 13Pro, with an image resolution of 3060×4080 pixels. During the image acquisition process, the handheld device was positioned within a range of 0.2 to 1.5 meters from the rice leaves, and rice leaf images under different lighting conditions, angles, and scales were collected, amounting to 2000 in total.

The dimensions of the sampled images were uniformly cropped to 640×640. Due to the existence of various circumstances such as variations in light intensity, noise, and blurriness in the outdoor rice field environment during collection, certain details in some areas of the collected images were lost. To accommodate the complex and variable real scenarios in outdoor detection, such as light and image capture angles, and to enhance the generalization ability and robustness of the model in complex scenarios, four image enhancement algorithms, namely Gaussian blur, mirror flip, salt and pepper noise, and random brightness, were employed to augment the dataset. The augmented dataset comprises 8000 images, as depicted in Figure 1. The training set, validation set, and test set were partitioned in an 8:1:1 ratio, with the training set containing 6400 images and both the test set and validation set each containing 800 images.

5.2 Analysis method

YOLOv8, as a single-stage object detection algorithm, omits the generation and classification steps of candidate regions and directly performs object classification and bounding box regression prediction on the input image. It surpasses two-stage detection algorithms in terms of detection speed. In this paper, with the single-stage object detection algorithm YOLOv8 as the baseline model, methods such as multi-scale feature fusion, attention mechanisms, small object feature extraction, and data augmentation are introduced to design a novel algorithm to tackle problems like the difficulty in differentiating rice leaf diseases and pests from the background and the false detection and missed detection resulting from minute diseases and pests. The main enhancements of the new algorithm are as follows: (1) To address the issue of extensive redundancy in the intermediate feature maps during the mainstream convolutional computation process, referring to the idea in GhostNet, and simultaneously, to enhance the capabilities of feature extraction and gradient flow, RepConv is employed in the gradient flow branch. A novel RGCSPELAN efficient aggregation module is designed, which elevates the detection speed and accuracy of the model. (2) An adaptive downsampling module ADown is incorporated into the neck network. It possesses a relatively strong adaptive learning capacity and can be adjusted differently based on various data scenarios. Moreover, it is a lightweight design structure that reduces the complexity of the model by minimizing the number of parameters. (3) A context anchor attention mechanism CAA is appended after the adaptive downsampling layer ADown, concentrating on extracting multi-scale local context information. (4) To enhance the positioning and classification performance of the detection head, referring to the concept of TOOD, a new task-aligned dynamic detection head TADDH is devised. Utilizing shared convolution reduces the number of parameters of the model, making it more lightweight. Furthermore, in response to the issue of different scales of detection targets processed by the three detection heads respectively, Scale layers are introduced into the three detection heads to enlarge or shrink the feature size. This effectively enhances the receptive field of the detection heads.

## VI. RESULTS AND ANALYSIS

6.1 The result of image acquisition by unmanned aerial vehicles

Through the analysis of unmanned aerial vehicle (UAV) images of rice at different growth stages, it was discovered that during the tillering stage, the rice plants were relatively short, and the leaf color was light; during the booting stage, the rice plants gradually grew taller, the leaf color deepened, and the panicles began to form; after the heading stage, the panicles gradually emerged, and the leaf color turned dark green; during the grain-filling stage, the panicles gradually turned yellow, and the grains became plump; at the maturity stage, the panicles turned completely yellow, and the leaves gradually wilted. These image characteristics offer significant reference bases for subsequent pest and disease identification.

By employing image processing technology and feature extraction algorithms, the images of rice plants infected with pests and diseases were analyzed. The results indicated that the rice plants infected with pests and diseases exhibited significant differences in color, texture, and other aspects compared with healthy plants. For instance, the leaves of rice infected with rice blast would present brown spots; the leaves of rice plants attacked by rice planthoppers would turn yellow, and the growth would be slow. Through visual analysis, the occurrence locations and degrees of pests and diseases could be observed intuitively.

6.2 Comparison of Pest and Disease Detection Results

By conducting a comparison between the results obtained from traditional monitoring approaches and those from unmanned aerial vehicle (UAV) monitoring methods, it was revealed that the accuracy and recall rates of the UAV monitoring method were both higher than those of the traditional ones. During the tillering and booting stages, the disparities between the two methods were not substantial; yet, during the heading and grain-filling stages, the superiority of the UAV monitoring method became more conspicuous. This is primarily attributed to the fact that as the rice plants develop, the symptoms of diseases and pests become more distinct, and the high-resolution cameras and advanced image processing algorithms搭载 on the UAVs can identify diseases and pests more precisely.

An analysis of the detection accuracy for different types of diseases and pests disclosed that for leaf diseases (such as rice blast), the accuracy of the UAV monitoring method was relatively high; whereas for boring pests (such as the Chilo suppressalis), since their damage mainly occurs inside the plants and is difficult to observe directly, the detection is more arduous and the accuracy is relatively lower. On the whole, the UAV monitoring method exhibited favorable performance in the detection of various diseases and pests.

### 6.3 The influence of environmental factors on monitoring results

Lighting conditions are one of the crucial factors influencing the image quality of unmanned aerial vehicles (UAVs). Under diverse light intensities, the color and texture of rice plants undergo alterations, thereby potentially affecting the accuracy of pest and disease identification. Experimental outcomes demonstrate that the accuracy of the UAV monitoring method is relatively high under adequate lighting conditions; conversely, it declines under insufficient lighting circumstances. Hence, in practical applications, monitoring should be executed during periods with favorable lighting conditions to the greatest extent possible.

Meteorological conditions (such as temperature, humidity, and rainfall) also exert an impact on the occurrence and development of pests and diseases. Environments with high temperatures and humidity are conducive to the proliferation and dissemination of pests and diseases; rainy weather might cause the expansion of the spread range of pests and diseases. Through the analysis of meteorological data, it is revealed that the incidence rate of pests and diseases is relatively high under weather conditions of high temperature and high humidity; whereas in dry and low-temperature weather conditions, the occurrence of pests and diseases is relatively less. Therefore, when undertaking pest and disease monitoring, a comprehensive analysis should be conducted in conjunction with meteorological conditions.

The disparity in topography and landforms also affects the monitoring efficacy of UAVs. For instance, in mountainous or hilly regions, due to significant terrain undulations, the flight paths of UAVs are restricted, potentially resulting in certain areas being unmonitored. Additionally, topography and landforms also influence the distribution of lighting and meteorological conditions, thereby indirectly influencing the occurrence of pests and diseases. Consequently, when conducting pest and disease monitoring in areas with complex topography and landforms, the monitoring plan needs to be adjusted in accordance with the actual situation.

### 6.4 Cost-benefit analysis

Traditional monitoring approaches entail a substantial investment of human, material, and financial resources. Manual inspections consume a considerable amount of time and energy; the purchase and maintenance of monitoring equipment also involve certain expenses. Furthermore, due to the low efficiency of manual inspections, the optimal timing for prevention and control might be missed, resulting in the exacerbation of pest and disease damage and an increase in control costs. According to statistics, the annual monitoring cost per mu employing traditional methods is approximately 1,040 to 3,120 yuan.

Although the drone monitoring method necessitates the acquisition of drones and related equipment, it can considerably reduce labor and time costs in comparison to traditional methods. Moreover, drones can be reused, presenting a higher cost-effectiveness in the long term. Estimations indicate that the annual monitoring cost per mu using the drone monitoring approach is approximately 200 to 500 yuan. Considering factors such as the service life and operational efficiency of drones, the actual cost might be even lower.

From an economic perspective, the drone monitoring method can promptly detect pest and disease problems, enabling the implementation of effective control measures, reducing pesticide usage and losses caused by pests and diseases. Simultaneously, it can enhance the yield and quality of rice, augmenting farmers' incomes. Taking into account both cost and benefit factors, the drone monitoring method holds distinct advantages. Additionally, it can bring about benefits in terms of reducing environmental pollution and social risks.

From a social perspective, the drone monitoring system, by constructing a pest and disease early warning model, can shorten the monitoring response time to one-fifth of that of traditional methods, significantly enhancing agricultural emergency management capabilities. The early disease identification accuracy rate based on hyperspectral imaging technology can reach over 92%, which is approximately 40 percentage points higher than manual visual inspection, allowing for a 10 to 15-day advancement of the control window. In terms of ecological benefits, the precise pesticide application system reduces pesticide usage by 30% to 50%. According to the 2024 experimental data from the Ministry of Agriculture and Rural Affairs, the pesticide residue in the soil of demonstration plots decreased by 42.7% year-on-year, and the biodiversity index of surrounding water bodies increased by 18.3%. Notably, by establishing a cloud-based agricultural database, the spatiotemporal information collected by drones can provide a continuously updated monitoring dataset for crop growth models. This digital asset will generate incalculable derivative value in the future development of smart agriculture.

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