

Application analysis of UAV remote sensing technology in agricultural pest monitoring

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ABSTRACT: *In the context of global food security challenges, agricultural pest control has become the core link to ensure stable and increased grain production. As the main wheat producing area in China, Henan Province has a continuous threat to grain production due to the high incidence of pests and diseases, and the disadvantages of low efficiency and narrow coverage of traditional monitoring methods are becoming increasingly prominent. With the advantages of efficiency, accuracy and flexibility, UAV remote sensing technology provides an innovative path for solving the dilemma of agricultural pest monitoring. This paper takes the main wheat producing areas in Henan Province as a research sample, combined with the actual regional agricultural production, analyzes the application logic of UAV remote sensing technology in pest and disease monitoring, and deeply discusses the enabling role and promotion value of UAV technology in agricultural production by sorting out the technical principles and analyzing the practical results, so as to provide theoretical and practical reference for promoting the digital transformation of agriculture and building a solid line of defense for food security.*

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I. INTRODUCTION

Agriculture is the foundation of the national economy, and food security is an important cornerstone of national security[1]. As a key risk factor restricting agricultural production, pests and diseases lead to a loss of about 10% of global grain production every year, and China's economic losses due to pests and diseases are also as high as tens of billions of yuan every year[2], which seriously threatens stable grain production and farmers' income. As the largest wheat producing area in the country, Henan Province accounts for more than a quarter of the country's total output[3], and the stability of wheat production is directly related to the overall situation of national food security[4]. However, Henan Province is affected by the temperate monsoon climate, with high temperature and high humidity in summer and cold and warm in winter, which provides favorable conditions for the breeding and spread of diseases and pests such as wheat stripe rust, gibbereliosis, and aphids.

Traditional agricultural pest and disease monitoring mainly relies on manual field inspections[5], which have disadvantages such as low efficiency, limited coverage, strong subjectivity of monitoring results, and prominent lag in early warning. Manual inspection not only requires a lot of labor costs, but also is difficult to accurately identify hidden dangers during the incubation period of pests and diseases, and often takes control measures after a large-scale outbreak of pests and diseases, resulting in increased control costs and excessive use of pesticides, which not only affects the quality and safety of agricultural products, but also causes damage to the ecological environment. In this context, UAV remote sensing technology, as an emerging means of agricultural monitoring, provides a breakthrough solution for agricultural pest monitoring with its efficient and flexible operation mode and accurate data collection capabilities, and has become an important technical support for promoting the transformation of traditional agriculture to precision agriculture and smart agriculture.

Analyzing the application of UAV remote sensing technology in agricultural pest monitoring is not only a discussion of the function and effectiveness of the technology itself, but also an in-depth analysis of the integration of technical logic and agricultural production laws, the coordination of technology promotion and rural governance, and the reconstruction of the value of science and technology empowerment and food security. This paper takes the main wheat producing areas of Henan Province as the research object, combined with the actual regional agricultural production, and analyzes the practical results, social value, promotion dilemmas and paths of technology application, aiming to comprehensively present the enabling role of UAV remote sensing technology in agricultural production, and provide theoretical basis and practical reference for promoting the widespread promotion of technology in the agricultural field.

II. The core principles and technical advantages of UAV remote sensing technology in agricultural pest monitoring

(1) Accurate perception based on spectral differences

The core logic of UAV remote sensing technology to monitor agricultural pests and diseases stems from the differences in spectral reflection characteristics caused by changes in physiological and morphological characteristics of crops under pest and disease attacks[6]. Healthy crop leaves are rich in chlorophyll and show specific laws in reflectivity in the visible and near-infrared bands. When crops are attacked by pests and diseases, the chlorophyll content of leaves decreases and the tissue structure is damaged, resulting in changes in leaf color, structure, water content[7], etc., and then changing their reflection, absorption and radiation characteristics of electromagnetic waves in different bands.

By carrying a variety of sensors such as multispectral, hyperspectral, visible light, and thermal infrared, drones can accurately capture the spectral information of crops in different wavelengths and build a multi-dimensional farmland monitoring data system[8]. These data can be analyzed by image processing algorithms and artificial intelligence models to accurately identify the types, occurrence degrees, distribution ranges and spread trends of pests and diseases, and realize early warning and accurate localization of pests and diseases. For example, in the early stage of wheat stripe rust, chlorosis spots will appear on leaves, and multispectral sensors can capture a significant decrease in the reflectivity of leaves in the near-infrared band.

(2) Significant advantages over traditional monitoring methods

Traditional manual inspections rely on manual foot inspections, and each person can only cover a few acres of farmland per day, and is limited by factors such as terrain and weather, and the monitoring cycle is long and inefficient, making it difficult to meet the monitoring needs of large areas of farmland. UAV remote sensing technology flies quickly at low altitudes, and a multi-rotor UAV can complete the monitoring operation of 15-20 acres of farmland per hour, and the operating area of fixed-wing drones can reach 50-80 acres per hour, which is dozens of times the efficiency of manual inspection. At the same time, drones can complete the data collection of large areas of farmland in a short period of time, transmit monitoring results in real time, greatly shorten the monitoring cycle, realize early detection and early warning of pests and diseases, effectively seize the "golden window period" of prevention and control, and avoid greater losses caused by the spread of pests and diseases.

Traditional manual inspections are easily affected by factors such as crop occlusion and complex terrain, and there are blind spots in monitoring, and the accuracy of manual identification of pests and diseases depends on the experience of inspectors, which is highly subjective and has large errors. The high-resolution sensors equipped with drones can achieve centimeter-level spatial resolution, clearly capture the subtle lesion characteristics of individual crops, and even identify areas where small pests gather. Multispectral and hyperspectral sensors can accurately capture the hidden characteristics of crop physiological changes and realize the early identification of pests and diseases. LiDAR technology can penetrate the branches and leaves of tall crops, construct a three-dimensional structure model of crops, comprehensively grasp the degree of damage caused by pests and diseases to the crop canopy, realize all-round and high-precision monitoring of farmland, and effectively make up for the blind spots and shortcomings of traditional monitoring methods.

Traditional manual inspections require a lot of manpower, long-term monitoring costs are high, and during the period of high incidence of pests and diseases, manual field operations need to be directly exposed to pesticides, facing harsh environments such as high temperature, high humidity, toxicity and harm, and there are serious health and safety risks. The equipment purchase and maintenance cost of UAV remote sensing technology is relatively low, and with the maturity of technology and the intensification of market competition, the equipment cost is declining, and small and medium-sized farmers and agricultural cooperatives can afford it. At the same time, drone operations do not require personnel to enter the field directly, realizing the separation of man and machine, completely avoiding the risk of pesticide exposure, and ensuring the life, health and safety of operators. In addition, UAV monitoring can reduce the blind use of pesticides, reduce pesticide waste and environmental pollution, and have both economic and ecological benefits.

The main wheat producing areas in Henan Province cover plains, hills and other terrains, and some remote plots and mountainous farmland are difficult to cover by traditional monitoring methods. UAVs have flexible take-off and landing capabilities and autonomous flight functions, which can flexibly adjust the flight path according to the topography of farmland and monitoring needs, are not limited by ground road conditions, and can quickly cover farmland with complex terrain, solving the problem of "dead corners" that are difficult to reach by traditional monitoring methods. At the same time, drones can be equipped with corresponding sensors according to the characteristics of different crop types and pests to achieve targeted monitoring and meet diversified agricultural monitoring needs.

III. Application practice and effectiveness analysis of UAV remote sensing technology

(1) Practical needs for pest control

As the largest wheat province in the country, Henan Province has a stable wheat planting area of more than 85 million mu, accounting for nearly a quarter of the country's total wheat production, and is the "ballast stone" of national food security. However, Henan Province's unique climatic conditions and planting structure make it a high-incidence area for wheat pests and diseases, including wheat stripe rust, gibbereliosis, powdery mildew, aphids, wheat spiders, etc. Among them, wheat stripe rust has the characteristics of fast spread, wide range of harm, and serious yield reduction, and once it breaks out, it is easy to spread to a large area of wheat fields in a short period of time. Wheat scab is prone to high incidence in high temperature and high humidity environments, which not only affects wheat yield, but also produces toxins and threatens the quality and safety of wheat[9].

Under the traditional monitoring mode, the monitoring of wheat pests and diseases in Henan Province mainly relies on manual inspection by grassroots agricultural technicians, which is not only inefficient, but also difficult to achieve comprehensive coverage during the peak period of pest outbreaks, which often leads to delays in control and reduces wheat yield. At the same time, traditional control methods rely on manual spraying of pesticides, and the low utilization rate of pesticides not only increases the cost of prevention and control[10], but also leads to soil and water pollution and damages the ecological environment of farmland. Therefore, the main wheat producing areas in Henan Province urgently need an efficient, accurate and green pest monitoring and control technology to solve the current dilemma of pest control and ensure stable and increased wheat yield and quality safety[11].

(2) Typical application scenarios of UAV remote sensing technology in Henan Province

In recent years, Henan Province has actively promoted the digital transformation of agriculture, widely promoted UAV remote sensing technology in the main wheat-producing areas, and formed a number of typical application models, covering the whole process of early warning of pests and diseases, precise pesticide application, and evaluation of control effects[12].

Early warning of pests and diseases: Seize the opportunity for prevention and control: In the main wheat-producing areas such as Nanyang and Zhumadian in Henan Province, local agricultural and rural departments have joined hands with science and technology enterprises to establish a UAV remote sensing monitoring network and regularly carry out low-altitude remote sensing monitoring during the critical period of wheat growth. By carrying multispectral sensors, drones can collect spectral data from wheat fields in real time, combined with artificial intelligence algorithm analysis, to accurately identify early signs of wheat stripe rust, gibbereliosis and other diseases and pests. For example, in wheat stripe rust monitoring, drones can identify subtle changes in leaf spectral parameters during the incubation period of the disease, issue early warnings 3-5 days in advance, and reserve sufficient control time for farmers. According to relevant data, after the adoption of UAV early warning technology, the response time for the prevention and control of wheat stripe rust in Henan Province has been greatly shortened, and the spread area of the disease has been significantly reduced.

UAVs are not only used for pest and disease monitoring, but also deeply integrated with precision pesticide application technology to form a closed-loop operation mode of "monitoring-decision-application". After monitoring and finding pests and diseases, the intelligent spraying system equipped with the drone can achieve precise variable application according to the heat map of pest distribution and GPS/RTK centimeter-level positioning technology. For areas with severe pests and diseases, drones spray high-concentration pesticides; For mild occurrence or healthy areas, reduce the amount of pesticide or do not apply it to avoid pesticide waste. Compared with traditional manual pesticide application, the amount of pesticides is reduced by 30%-50%, and the utilization rate of pesticides is increased to more than 60%, which not only reduces the cost of prevention and control, but also reduces the pollution of pesticides to soil and water, and protects the ecological environment of farmland. At the same time, the UAV flight function can adapt to wheat fields with different terrains, ensuring that the droplets evenly cover the wheat canopy and improve the application effect.

UAV remote sensing technology can also be used to dynamically evaluate the effectiveness of pest control. Before and after pesticide spraying, the drone collects remote sensing images of farmland, evaluates the changes in the occurrence of pests and diseases through comparative analysis of image data, and judges the effectiveness of control measures. For example, in the control of wheat pests and diseases in Xinyang, Henan Province, the local agricultural technology department used drones to carry out review and monitoring 1-3 days after application, and adjusted the control plan in time by analyzing leaf spectral data and the distribution of pests and diseases to avoid repeated or insufficient application. This dynamic evaluation model provides data support for the scientific formulation of control strategies, promotes the transformation of pest control from empirical to data-based, and improves the accuracy and scientificity of prevention and control.

(3) The empowerment effect of UAV remote sensing technology on agricultural production in Henan Province

The efficient monitoring and precise control of UAV remote sensing technology have effectively reduced the threat of pests and diseases to wheat yield, and provided a solid guarantee for the stable and increased wheat yield in Henan Province. Taking wheat production in Henan Province in 2023 as an example, the average yield per mu of wheat increased by 5%-8% compared with the traditional control area using drones, and the province has reduced the loss of wheat production by billions of yuan, effectively ensuring national food security and consolidating the core position of Henan Province as the main wheat producing area in the country.

The application of UAV remote sensing technology has greatly reduced the labor cost and pesticide cost of agricultural production. Traditional manual inspection and pesticide application require a lot of labor, especially during the period of high incidence of pests and diseases, and labor costs remain high. The operation efficiency of drones is high, which can replace a large amount of labor and reduce manpower input. At the same time, precise pesticide application reduces pesticide waste and reduces pesticide procurement costs. According to estimates, after the use of drone technology in the main wheat producing areas of Henan Province, the cost of pest control per mu of farmland has been reduced by 20%-30%, and the planting income of farmers has been significantly improved, which has stimulated farmers' enthusiasm for growing grain and injected impetus into sustainable agricultural development.

Drone precision pesticide application technology reduces the overuse of pesticides, reduces pesticide pollution to soil, water and air, and protects farmland ecosystems. The utilization rate of traditional artificial pesticides is only about 30%, and a large amount of pesticides are lost to the environment, causing problems such as soil compaction and water eutrophication. The pesticide utilization rate of drone application has been increased to more than 60%, which greatly reduces pesticide residues and environmental pollution, and at the same time avoids the damage of pesticide drift to surrounding non-target organisms, promotes the coordinated development of agriculture and the ecological environment, and promotes the transformation of agriculture in Henan Province to a green and sustainable direction.

The application of UAV remote sensing technology has promoted the process of agricultural data management in Henan Province. The massive monitoring data collected by drones can be connected to the local agricultural big data platform, combined with meteorological data, soil data, crop growth data, etc., to build a pest monitoring and early warning model to achieve accurate prediction and scientific prevention and control of the occurrence of pests and diseases. This data-driven management model breaks the limitations of traditional agriculture relying on experience and decision-making, improves the level of refinement and intelligence of agricultural management, and lays a technical foundation for the development of agricultural modernization in Henan Province.

IV. The promotion value of UAV remote sensing technology

(1) Superposition of multiple benefits under technology empowerment

The promotion of UAV remote sensing technology not only reduces agricultural production costs, but also improves the quality and yield of agricultural products, bringing significant economic benefits to the agricultural industry. From the perspective of farmers, UAV technology reduces the cost of pest control, improves wheat yield and quality, and increases farmers' planting income. From the perspective of the agricultural industry, the large-scale application of UAV technology has promoted the professional and market-oriented development of agricultural plant protection services, spawned a number of professional UAV plant protection service enterprises, driven the development of related industrial chains, created a large number of jobs, and injected new momentum into the revitalization of rural industries. At the same time, the application of drone technology has improved the quality and safety level of agricultural products, reduced pesticide residues, enhanced the market competitiveness of wheat in Henan Province, and helped the agricultural industry develop in the direction of high quality.

Food security is the cornerstone of social stability, and the promotion of UAV remote sensing technology in Henan Province directly ensures the stable production and increase of wheat production, and builds a solid line of defense for national food security, which is of great social significance. For rural society, stable grain production ensures farmers' basic income, reduces income fluctuations caused by pests and diseases, reduces the risk of rural poverty, and promotes the stability of rural society. In addition, the promotion of drone technology requires a large number of operation and maintenance personnel, providing new employment opportunities for rural labor, attracting some young people to return to their hometowns for employment, alleviating the problem of rural labor loss, and providing support for the revitalization of rural talents. At the same time, the popularization of UAV technology has promoted the popularization and dissemination of agricultural knowledge, improved the scientific and technological literacy of farmers, and promoted the scientific and technological progress and concept update of rural society.

The precise monitoring and application of UAV remote sensing technology has greatly reduced the use of pesticides, reduced agricultural non-point source pollution, protected the ecological environment of farmland, and practiced the concept of green agricultural development. As a major agricultural province, agricultural non-point source pollution is one of the important challenges of ecological and environmental protection. The promotion of UAV technology has reduced pesticide pollution from the source, improved soil quality, protected the water environment, maintained the biodiversity of farmland ecosystems, and provided strong support for the construction of rural ecological livability. At the same time, the promotion of green production methods has also enhanced farmers' awareness of ecological and environmental protection, promoted the formation of a good atmosphere for green development in rural areas, and helped the construction of rural ecological civilization.

(2) The social logic and humanistic care behind the promotion of technology

The promotion of UAV remote sensing technology is not only a technical innovation, but also a reconstruction of traditional agricultural production relations. Traditional agricultural production relies on human labor, with low production efficiency and high labor intensity, and farmers are in a state of passive response to pests and diseases in agricultural production. The application of UAV technology has liberated farmers from heavy field labor, transformed farmers from traditional manual laborers to technical operators and managers, and transformed agricultural production methods from extensive to precise and intelligent. This transformation not only improves agricultural production efficiency, but also changes farmers' production concepts and professional roles, promotes the evolution of agricultural production relations in the direction of modernization and specialization, and lays a social foundation for the development of agricultural modernization.

The promotion of UAV remote sensing technology and the deep integration of rural governance have become an important means to improve the efficiency of grassroots governance. In the monitoring and control of pests and diseases, the data obtained by the grassroots agricultural and rural departments through drones realizes the precise management of farmland in the region and improves the overall coordination ability of pest prevention and control. At the same time, the UAV monitoring data is connected to the rural governance big data platform, which can realize the dynamic management of farmland information, provide data support for land transfer, agricultural subsidy distribution, agricultural insurance claims and other work, and improve the accuracy and transparency of grassroots governance. In addition, in the process of promoting UAV technology, the grassroots government has shortened the distance with farmers by organizing technical training and building service platforms, enhanced the communication and interaction between the government and farmers, improved the credibility and service capabilities of grassroots governments, and promoted the transformation of rural governance to refinement and intelligence.

The promotion of UAV remote sensing technology reflects the organic unity of scientific and technological empowerment and humanistic care. The ultimate purpose of technology promotion is to serve farmers and improve their quality of production and life. In the process of technology promotion, the threshold for farmers to use drone technology is lowered by carrying out free training, subsidizing equipment purchases, providing technical services, etc., ensuring that ordinary farmers can enjoy technical dividends and ensuring the dominant position of farmers in agricultural production. At the same time, the application of drone technology reduces the labor intensity of farmers, reduces the risk of pesticide exposure, ensures the health and life safety of farmers, and reflects the humanistic care for farmers. This combination of science and technology and humanities makes technology promotion not only have economic value, but also has social temperature, so that farmers can feel dignity and happiness while enjoying scientific and technological progress, and promote agricultural development to truly benefit farmers.

V. Challenges and coping strategies for the promotion of UAV remote sensing technology in Henan Province

(1) Practical challenges faced in the promotion process

Some farmers in Henan Province are older and have a low level of education, lack of understanding of the principles and operation methods of UAV remote sensing technology, doubts about the application effect of the technology, and worry about the complexity of equipment operation and high maintenance costs, resulting in low acceptance of technology. Especially in remote rural areas, information dissemination is relatively lagging behind, and farmers' awareness of new technologies is insufficient, which restricts the popularization of drone technology.

Although the cost of UAV equipment has decreased compared with the past, for ordinary small farmers, the purchase cost of a single UAV is still high, and the subsequent operating costs such as equipment maintenance, battery replacement, and sensor calibration should not be underestimated. In addition, the operation of drones requires professional technical personnel, and the lack of professional and technical personnel in rural areas makes it difficult for farmers to operate drones independently.

At present, the technical standards, data collection specifications, and pest identification algorithms of UAV remote sensing technology in agricultural pest monitoring have not yet formed a unified standard system, and the UAV equipment produced by different enterprises and the monitoring data in different regions lack compatibility, resulting in the difficulty of data sharing and integration, which affects the large-scale promotion of technology and the unified evaluation of application effects. At the same time, the norms of UAV flight management and safety supervision are not perfect, and there are certain flight safety hazards.

The promotion of UAV technology requires the support of a complete technical service system, including equipment operation training, fault maintenance, data interpretation, etc. However, some grassroots rural areas in Henan Province, especially remote townships, lack professional technical service institutions and personnel, and it is difficult for farmers to solve problems in the process of technology use in a timely manner, resulting in a great reduction in the application of technology. In addition, grassroots agricultural technicians have insufficient mastery of UAV technology, making it difficult to provide effective technical guidance for farmers, which restricts the speed of technology promotion.

(2) Coping strategy: build a diversified and collaborative promotion system

The government should increase the publicity of UAV remote sensing technology, and intuitively demonstrate the application effect and operation methods of the technology to farmers by holding on-site demonstrations, technical training lectures, and distributing publicity materials, so as to eliminate farmers' doubts. At the same time, according to the cultural level and technical acceptance ability of different farmers, carry out hierarchical and classified technical training, establish a joint training mechanism of "government + enterprise + agricultural technicians", cultivate a group of backbones of farmers who understand technology and know how to operate, play a demonstration and leading role, and gradually improve farmers' awareness and acceptance of UAV technology.

The government should introduce targeted support policies to subsidize farmers to purchase UAV equipment and carry out UAV plant protection services, so as to reduce the equipment purchase and operating costs of farmers. At the same time, financial institutions are encouraged to provide low-interest loans for UAV plant protection service enterprises and farmers to alleviate financial pressure. In addition, support the development of professional plant protection service enterprises, reduce service costs through large-scale operation, and provide small farmers with preferential plant protection services, so that more farmers can enjoy the convenience of drone technology.

Relevant departments should accelerate the formulation of technical standards and specifications for UAV remote sensing technology in agricultural pest monitoring, unify data collection formats, pest and disease identification algorithms, equipment performance requirements, etc., ensure compatibility between different equipment and systems, and promote data sharing and integration. At the same time, improve the UAV flight management and safety supervision system, clarify the regional restrictions, height restrictions, and safety operation specifications of UAV flight, strengthen flight safety supervision, and ensure the safety and orderliness of UAV operations.

Strengthen the construction of grassroots agricultural technology service teams, improve the mastery of UAV technology by agricultural technicians through training, and ensure that each township has professional agricultural technicians who can provide technical guidance to farmers. At the same time, enterprises are encouraged to cooperate with grassroots governments to establish technical service stations in rural areas, provide one-stop services such as equipment maintenance, data interpretation, and technical consultation, and solve farmers' worries about technology use. In addition, build an online technical service platform, integrate technical experts, agricultural technicians and other resources, provide remote technical guidance for farmers, and improve the coverage and response speed of technical services.

VI. Conclusions and prospects

As an efficient, accurate and green agricultural monitoring technology, UAV remote sensing technology has shown significant technical advantages and multiple values in the application practice of the main wheat producing areas of Henan Province, which not only effectively solves the dilemma of traditional pest monitoring and control, ensures the stable and increased production of wheat, promotes the green transformation of agriculture, but also provides strong support for the digital transformation of agriculture, the improvement of rural governance efficiency, and the improvement of farmers' production and quality of life. From the perspective of liberal arts, the promotion of UAV remote sensing technology is not only a technical innovation, but also a reconstruction of agricultural production relations, rural governance models, and the main position of farmers, reflecting the organic unity of scientific and technological empowerment and humanistic care, and injecting new social connotations and value dimensions into the development of agricultural modernization.

Although the current promotion of UAV remote sensing technology in Henan Province still faces challenges in terms of technical cognition, cost pressure, standards and specifications, and service systems,

these challenges will be gradually solved with the continuous maturity of technology, the continuous improvement of policies, and the gradual improvement of the service system. In the future, UAV remote sensing technology will be deeply integrated with artificial intelligence, big data, Internet of Things and other technologies to form a full-process intelligent agricultural plant protection system of "monitoring-early warning-prevention-evaluation", further improve the accuracy and timeliness of pest monitoring, and promote the development of agricultural production in a more intelligent, green and refined direction.

At the same time, the promotion of UAV remote sensing technology will further deepen the integration of technology and agriculture, science and technology and rural areas, promote the transformation of rural governance to digitalization and refinement, promote the revitalization of rural talents and the construction of ecological civilization, and provide solid technical support and guarantee for comprehensively promoting rural revitalization, ensuring national food security, and realizing agricultural modernization. Driven by the dual drive of scientific and technological empowerment and humanistic care, UAV remote sensing technology will surely become an important force in promoting the high-quality development of China's agriculture and contribute greater value to the construction of a safe, efficient and green modern agricultural system.

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