The Application and Challenges of Unmanned Aerial Vehicles in Smart Agriculture Monitoring and Irrigation Technology

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**Abstract.** This paper takes the intelligent unmanned aerial vehicle system equipped with multispectral sensors as the core research object, systematically explores the application scenarios of precise monitoring and intelligent irrigation of this technology in the field of modern smart agriculture, as well as the key challenges it faces in the process of technology promotion. The research focuses on analyzing the structural design features and detection technologies of unmanned aerial vehicles (UAVs) suitable for farmland irrigation scenarios, including the study of detection technologies based on advanced data acquisition methods such as multispectral imaging. It systematically assesses its ability to identify and monitor the growth status of crops, soil moisture, and vegetation coverage, and analyzes the benefits of technology implementation in combination with actual cases. Unmanned Aerial Vehicle (UAV) irrigation and detection technology is confronted with challenges such as high cost, poor adaptability to complex environments, and insufficient professional training. It is necessary to promote its popularization and application by reducing equipment cost, optimizing anti-interference design, and strengthening technical training.

# Introduction

Traditional agricultural irrigation techniques mainly rely on manual experience for management, and there are prominent problems such as water resource waste, low irrigation efficiency, and high labor costs. With the intensification of climate change, the threats of frequent droughts and water shortages are becoming increasingly severe, and the limitations of traditional irrigation models are further exposed. Meanwhile, the shortage and aging trend of the rural labor force make it highly necessary to achieve the intelligent transformation of agricultural production through technological innovation. The application of unmanned aerial vehicle (UAV) technology provides a brand-new technical path for agricultural irrigation. This technology not only reduces the reliance of agricultural production on manual labor but also can adapt to the management needs of complex terrains and large-scale farmlands, providing important support for the sustainable development of agriculture. In recent years, new quality productivity technologies have been accelerating the transformation of traditional agriculture to smart agriculture.

Existing research focuses on the technical application and practical challenges of unmanned aerial vehicles (UAVs) in agricultural monitoring and irrigation. In areas where drones are used for precise pesticide spraying, the amount of pesticides used has decreased by approximately 32%, crop yields have increased by 23%, and the drone irrigation system can precisely control the irrigation volume, improve irrigation efficiency, and effectively reduce the waste of water resources [1]. From a technical perspective, Sun Sheng et al. analyzed that the application of technologies such as multispectral remote sensing has significantly improved the accuracy of crop growth monitoring, soil moisture assessment, and disaster early warning. The established prediction model of crown temperature difference - soil moisture content (R²=0.64) has practical value and can provide a quantitative basis for precise irrigation. Especially, the thermal imaging technology of unmanned aerial vehicles has significantly improved the monitoring efficiency [2]. Song Zhishuang obtained information about the sunflower farmland based on the multispectral remote sensing images of unmanned aerial vehicles. The average pixel accuracy and average intersection union ratio of the proposed improved DeepLab V3+ deep semantic segmentation method have reached 93.06% and 87.12% respectively, which can be improved by 17.75% and 20.8% respectively compared with the traditional support vector machine method based on manual design features and sliding window sampling [3]. At the same time, attention should be paid to aspects such as technical limitations (such as endurance, adaptability to complex environments), economic costs (equipment purchase and maintenance expenses), and social issues (data privacy protection, farmers' acceptance of technology) in the promotion of unmanned aerial vehicles.

This paper explores the application research of multispectral remote sensing unmanned aerial vehicles (UAVs) in smart agriculture monitoring and irrigation, with a focus on analyzing the monitoring capabilities of their structural design, multispectral imaging, and other detection technologies for crop, soil, and vegetation. It assesses economic benefits in combination with practical cases and discusses existing problems and development trends.

# Unmanned Aerial Vehicle (UAV) Mechanisms in Smart Agriculture

In smart agriculture, unmanned aerial vehicle (UAV) mechanisms and detection technologies work collaboratively through multiple components to achieve scientific and intelligent agricultural management. Firstly, the aircraft body utilizes an advanced flight control system to ensure that the unmanned aerial vehicle can fly stably and precisely position itself in complex environments [4]. Secondly, the sensor unit, through the high-precision sensors it is equipped with, such as multispectral cameras and thermal infrared cameras, collects information on the growth status of crops and soil moisture, providing detailed data for monitoring crop health [4]. The data transmission system transmits the data collected by the sensors in real time, ensuring the timeliness and continuity of the data and guaranteeing the timeliness and accuracy of the information [4]. Finally, the ground control station is responsible for receiving, processing, and analyzing data, generating irrigation strategies, providing a scientific basis for agricultural management, helping farmers make wiser decisions, and improving agricultural production efficiency [4].

The unmanned aerial vehicle (UAV) equipped with an irrigation device is an integrated intelligent agricultural equipment. By combining the precise irrigation system with the UAV platform, it achieves efficient and flexible management of farmland water and fertilizer. This innovative structure not only significantly enhances the efficiency of water resource utilization but also provides a mobile and precise irrigation solution for smart agriculture, effectively addressing the problems of poor uniformity and high labor intensity existing in traditional irrigation methods.

Henan Puhe Agricultural Science and Technology Co., Ltd. has designed a type of unmanned aerial vehicle (UAV). The agricultural irrigation structure of this UAV mainly consists of the top plate of the UAV (including the control box and the driving blade), the bottom placement box (for storing liquid), and the irrigation system (including the irrigation pipe with the spray port and the installation part). Its working principle is that the irrigation pipe is connected to the placement box through the installation part. The liquid is sprayed out from the multi-directional nozzle through the irrigation pipe. When the unmanned aerial vehicle is flying, the driving blades will not interfere with the direction of the water mist, achieving precise and efficient multi-directional irrigation [5].

Lanzhou Qianyuan Ecological Technology Co., Ltd. has designed a water-spraying unmanned aerial vehicle. The mechanical structure of the unmanned aerial vehicle mainly consists of ‌ a storage tank, an infusion tube, a spray head, a wing, an arm, a main frame, and a central control box ‌. The working principle is that the liquid storage tank is divided into several independent liquid storage chambers by partitions set inside. Each liquid storage chamber is connected to the spray head through a liquid delivery pipe to achieve independent transportation and spraying of different liquid medicines. The central control system in the central control box controls the flight of the unmanned aerial vehicle and the spraying operation of the irrigation and spraying components, thereby enabling the irrigation and spraying of different solutions at the same time and improving the efficiency of irrigation and spraying [6].

The comparative analysis of the two schemes reveals that both have common advantages in precise irrigation and intelligent control, and both can improve the utilization rate of water resources and achieve automated operations. Meanwhile, the former may have issues with endurance and terrain adaptability, while the latter may need improvement in terms of spraying stability and anti-clogging. Both may face common problems such as high cost and insufficient durability verification. Subsequent research needs to strengthen field tests.

# Monitoring Technology

## Soil Moisture Monitoring

UAVs equipped with multispectral and infrared cameras can monitor the soil moisture in farmland in real time. Multispectral cameras reflect humidity by analyzing vegetation and land types through different bands, while infrared cameras provide soil temperature and vegetation growth basis through the distribution of surface heat. After data processing, high-resolution humidity images are generated to help farmers precisely adjust irrigation and fertilization, achieving increased production and efficient resource utilization. This technology saves water and reduces costs by adjusting the irrigation system in real time, promoting sustainable agricultural development [7].

Based on the experimental data in the walnut orchard of Jiyuan City, Henan Province, Sun Sheng obtained the canopy temperature through the fixed thermal infrared imager (A310f) and the unmanned aerial vehicle thermal imaging system (TC640), and measured the moisture content of the key soil layer at 40-60 cm by combining the ring knife method and the EC-5 sensor. After preprocessing with FLIR Tools and Matlab, the crown temperature difference (ΔT) and the relative moisture content of the soil (RWC) were extracted as core variables. The prediction equations for the two-year growing season were constructed using multiple linear regression (R²=0.57 in 2016 and R²=0.69 in 2017). Principal component analysis was used to determine RWC (contribution rate 75%) and solar radiation (Ra, 25%) as the dominant factors. Finally, a simplified univariate model RWC= -0.032 ΔT+0.599 (R²=0.64, RMSE=0.04) was established, achieving accurate prediction of soil moisture based on thermal infrared features. A soil moisture prediction model was established with the crown temperature difference as the independent variable and the relative soil moisture content as the dependent variable. The model has a good fitting accuracy (R²=0.64) and was verified by the measured data (R²=0.61) [2].

The thermal infrared imaging fusion method proposed in this study shows significant advantages in the moisture monitoring of walnut orchards. Through the collaborative application of the fixed thermal imager and the unmanned aerial vehicle (UAV) system, the seamless conversion from the single-plant scale model to regional moisture diagnosis was achieved for the first time. The established prediction model of crown temperature difference-soil moisture content (R²=0.64) has practical value and can provide a quantitative basis for precise irrigation. Especially, the UAV thermal imaging technology has significantly improved the monitoring efficiency. However, this method still has several limitations. The model accuracy is greatly disturbed by environmental factors (such as solar radiation and wind speed fluctuations), and the prediction stability needs to be strengthened. The actual measurement of soil moisture content relies on the traditional ring knife method and EC-5 sensors, which have problems such as high labor costs and accumulated systematic errors. Furthermore, the complete elimination of soil background interference during the extraction of canopy temperature has not been achieved yet, which may affect the accuracy of region-scale diagnosis [2].

## Farmland Information Monitoring

Song Zhishuang obtained information about the sunflower farmland based on the multispectral remote sensing images of unmanned aerial vehicles. This study combined deep learning algorithms to comprehensively obtain information on sunflower fields. In terms of the classification of sunflower planting areas, by improving the DeepLab V3+ deep semantic segmentation model, integrating the vegetation index feature map, and replacing the ReLU function with the Swish function as the activation function, high-precision identification of sunflower planting areas was achieved. The average pixel accuracy and the average intersection union ratio reached 93.06% and 87.12%, respectively. Compared with the traditional SVM method, it has increased by 17.75% and 20.8% respectively [3]. In the aspect of sunflower growth period recognition, a method based on a pixel-level deep semantic segmentation model combined with block-level ROI region calculation was proposed. By introducing the inter-class difference weight loss function, the recognition accuracy was significantly improved, reaching 89.02%[3]. In the field of sunflower fall detection, by combining visible light with multispectral images through image fusion technology and improving the SegNet model, and adopting layer-jumping connection and conditional random field optimization, accurate recognition of fallen sunflowers was achieved. The recognition accuracy reached 89.8% and 83.3%, respectively, on non-fused and fused images [3].

The above-mentioned research fully utilized the rich spectral information of unmanned aerial vehicle (UAV) multispectral remote sensing images and the powerful feature extraction capabilities of deep learning algorithms, achieving high-precision and rapid acquisition of sunflower farmland information. By improving the model and algorithm, the accuracy of planting area classification, growth period identification, and lodging detection was significantly enhanced [3]. However, this study also has certain limitations. For example, the recognition accuracy in special environments such as tree shadow areas needs to be improved, and the recognition effect of the model on sparse areas and weak features of crops still needs to be further optimized [3]. Furthermore, although the pixel-level classification accuracy has been improved to a certain extent, there is still considerable room for improvement to meet the demands of more refined agricultural management. Future research can further explore better deep learning models to enhance recognition performance in special environments and refine pixel-level classification accuracy, providing more comprehensive technical support for the precise management of sunflower farmland [3].

## Growth Dynamic Monitoring

Xie Ziang utilized low-altitude unmanned aerial vehicle remote sensing technology and combined it with the AquaCrop crop model to construct a winter rapeseed growth monitoring and yield simulation system [8]. The high-resolution canopy images obtained through the unmanned aerial vehicle platform were used to establish the dynamic growth curves of winter rapeseed under different sowing periods and density scenarios. Based on the improved shape model method, precise monitoring of the four key phenological stages from sowing to flowering of winter rapeseed was achieved, and the overall phenological monitoring accuracy reached RMSE=3 days [8]. Furthermore, through the coupling of field experiment data with the AquaCrop model, the calibration of localized parameters of the model was completed, and the simulation ability of the model for the phenology, canopy coverage (CC), biomass, and yield of winter rapeseed under different scenarios was evaluated [8]. The research results show that the AquaCrop model achieved high simulation accuracy in medium and high density scenarios. The simulated RMSE of canopy coverage was 7-22%, and the simulated RMSE of biomass and yield was 0.8-2.1t/ha and 2.7-15.7%, respectively [8].

The research combines low-altitude unmanned aerial vehicle (UAV) remote sensing with crop models, providing strong technical support for smart agricultural irrigation [8]. Unmanned Aerial Vehicle (UAV) remote sensing technology, with its characteristics of high timeliness and high resolution, has achieved real-time monitoring of the growth dynamics of winter rapeseed, providing key data support for precise irrigation. The introduction of the AquaCrop model, by simulating the growth process and yield of crops, offers a scientific basis for irrigation decisions [8]. However, the research also found that the AquaCrop model overestimated the growth potential of winter rapeseed by approximately 40% in low-density scenarios, and the model had certain deviations in the simulation of climatic days. These deficiencies limited the application of the model in complex agricultural environments. Future studies need to further optimize the model parameters to improve the applicability and accuracy of the model in various scenarios. To better serve the practice of smart agricultural irrigation [8].

# Discussion

## Challenges Faced by Unmanned Aerial Vehicle Irrigation and Detection

In the field of unmanned aerial vehicle (UAV) irrigation and detection, although the technology has shown great potential, it still faces multiple challenges. First of all, the technical cost is the key factor restricting the wide application of unmanned aerial vehicle (UAV) irrigation and detection technology. High-performance unmanned aerial vehicles and their supporting equipment are relatively expensive. For small-scale farmers, the initial investment cost is large, which limits the popularization speed of the technology. In addition, when drones operate in complex farmland environments, they are prone to being affected by obstacles, which can lead to equipment damage or malfunction, increasing the cost of maintenance and repair. Secondly, insufficient technical training is also a major problem. At present, there is a general shortage of professional unmanned aerial vehicle (UAV) operation and maintenance personnel, which affects the effective application of the technology. Farmers and agricultural technicians need to receive professional training to enhance their drone operation skills and plant protection knowledge, ensuring the correct application of the technology.

## Development Trends of Unmanned Aerial Vehicle Irrigation and Detection

With the deep integration of technologies such as artificial intelligence, big data, and the Internet of Things, drones will become more intelligent and automated. In the future, drones will be capable of collecting and analyzing farmland data in real time, precisely controlling the amount of irrigation and fertilization, and achieving precise management of water and fertilizer integration. Meanwhile, the drones will also be equipped with more advanced sensors and detection devices, which can monitor the growth status and pest and disease conditions of crops in real time, providing more accurate and efficient decision support for agricultural production. Drones can also play a role in irrigation by improving the efficiency of microbial water quality monitoring, supporting the estimation of water quality parameters, assisting in irrigation decision-making, and reducing the input of human and material resources, providing strong support for the safe management of irrigation water sources [9].

With the continuous advancement of technology and the support of policies, the field of unmanned aerial vehicle (UAV) irrigation and detection will embrace a broader development prospect. On the other hand, the government will increase its support for unmanned aerial vehicle (UAV) plant protection technology. Through fiscal subsidies, tax incentives, and other policy measures, it will reduce the technology introduction and upgrading costs for farmers and enterprises, and promote the wide application and sustainable development of the technology. In addition, with the improvement of agricultural mechanization and the strengthening of agricultural information management, unmanned aerial vehicle (UAV) irrigation and detection technology will be deeply integrated with other agricultural technologies, jointly promoting the rapid development of modern agriculture.

# Conclusion

The application of unmanned aerial vehicles (UAVs) in smart agricultural irrigation and monitoring technologies has achieved remarkable results. UAVs equipped with intelligent irrigation devices have brought about efficient changes to modern agriculture. By integrating precise spraying systems and intelligent navigation technologies, UAVs can autonomously perform irrigation tasks in complex terrains and vast farmlands based on preset programs or remote instructions. Drones support more scientific and efficient irrigation decisions and management by providing precise monitoring data on the moisture status of crops during irrigation, which is of great significance for improving agricultural production efficiency, conserving water resources, and protecting the environment [10]. By being equipped with multi-spectral, thermal imaging, and other sensors, the unmanned aerial vehicle (UAV) can monitor soil moisture, vegetation detection, crop growth conditions, etc., in real time, and generate precise irrigation demand heat maps or prescription maps. Through variable control technology, the UAV can dynamically adjust the spraying intensity according to the water demand of different plots, effectively avoiding water waste and reducing the risk of excessive use of chemical fertilizers and pesticides.

# References

1. Y. Wang, Shanxi Science and Technology News, B06 (2024).
2. S. Sun, J. Zhang, P. Meng, Transactions of the Chinese Society of Agricultural Engineering **34**(16), 89-95 (2018).
3. Z. Song, "Information acquisition of sunflower farmland based on unmanned aerial vehicle multispectral remote sensing images," Ph.D. thesis, Northwest A&F University, 2021.
4. J. Zhang and H. Yan, Hebei Agricultural Machinery (02), 19-21 (2025).
5. Henan Puhe Agricultural Science and Technology Co., Ltd., Chinese Patent CN202123143240.1 (May 27, 2022).
6. Lanzhou Qianyuan Ecological Technology Co., Ltd., Chinese Patent CN202011464250.2 (March 16, 2021).
7. S. Zhang, Agricultural Machinery (10), 84-86 (2024).
8. Z. Xie, "Growth monitoring and yield simulation of winter rapeseed based on low-altitude unmanned aerial vehicle remote sensing," Ph.D. thesis, Yangzhou University, 2023.
9. B. Morgan, M. Stocker, J. Valdes-Abellan et al., Science of the Total Environment **716**, 135757 (2020).
10. J. Coulombe, P. Brown, S. White et al., Acta Horticulturae **1279**, 271-278 (2020).