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Drone Technology for Crop Disease Resistance: Innovations and Challenges

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Drones have been used for diverse application purposes in precision agriculture and new ways of using them are being explored. Many drone applications have been developed for different purposes such as pest detection, crop yield prediction, crop spraying, yield estimation, water stress detection, land mapping, identifying nutrient deficiency in plants, weed detection, livestock control,

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protection of agricultural products and soil analysis. Drones can create georeferenced maps that pinpoint the exact location of disease outbreaks within a field. These maps help farmers and agronomists monitor disease progression and plan targeted interventions. Drone operations are highly dependent on weather conditions. High winds, rain, and fog can hinder drone flights and affect the quality of images captured. Addressing technical limitations, regulatory and safety concerns, economic barriers, and data management issues will be crucial for the widespread adoption of drones in agriculture. By overcoming these challenges, drone technology can become a vital tool in sustainable and effective crop disease management.

Keywords: Crop disease management; agricultural products; drones; soil analysis.

1. INTRODUCTION

1.1 The Operational Mechanism of Drones for Plant Disease Detection

Drones, unmanned aerial vehicles, operate autonomously or via remote control, revolutionizing precision agriculture. These aerial platforms use high-resolution sensors to survey agricultural landscapes, including hazardous or inaccessible areas traditionally challenging for manned aircraft or satellites. Agricultural drones are broadly categorized into fixed-wing, rotary-wing (multirotor), and hybrid Vertical Take-Off and Landing (VTOL) types, each offering distinct advantages in agricultural applications Li et al., [1], Zhang et al., [2], Zheng et al., 2019; Chen et al., [3], Wang et al., [4].

1.2 Drone Systems for Plant Disease Detection

Drone systems for plant disease detection typically comprise four stages, illustrated in Fig. 1. This process involves data acquisition, preparation, training, and prediction. Drones equipped with advanced sensors and GPS capabilities capture high-quality images essential for disease assessment Zhang et al., [5], Zhou et al., 2018.

1.3 Image Processing and Disease Classification

The plant disease detection model follows a structured approach, involving image acquisition, preprocessing, segmentation, feature extraction, and classification. Initially, drones capture images crucial for creating a dataset[6-8]. Image preprocessing, including noise reduction and resizing, enhances image quality for accurate disease analysis Zhang et al., [5], Jiang et al., [9], Liu et al., [10].

Image segmentation divides images into distinct regions, aiding in detailed feature extraction. Features like shape, color, and texture are pivotal in identifying various crop diseases based on visual differences in leaf patterns. Traditional machine learning and deep learning techniques distinguish themselves in feature extraction methods, with deep learning automating this process more effectively Zhang et al., [5], Xu et al., 2017; Wang et al., 2016.

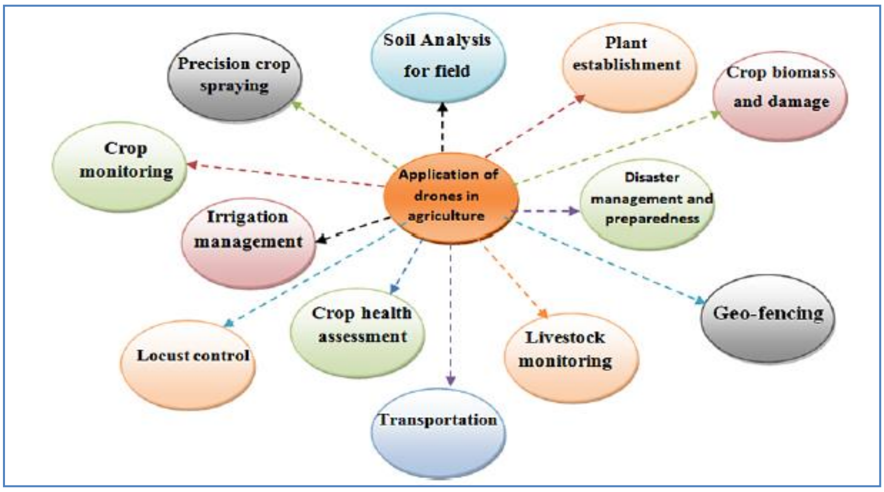

Fig. 1. Application of drone technology in agriculture

1.4 Spectral Imaging and Disease Severity Assessment

Drones equipped with multispectral cameras capture images in narrow spectral bands beyond visible light. These images allow for the calculation of spectral indices like NDVI, which correlates directly with plant health and disease severity. Multispectral imagery has been instrumental in monitoring diseases like rice sheath blight caused by *Rhizoctonia solani* at the field scale Chen et al., [11], Li et al., [12], Yang et al., 2019; Zhang et al., [13].

2. ROLE OF DRONE TECHNOLOGY IN INSECT PEST MANAGEMENT

2.1 Introduction of Drone Technology

Pest management is a crucial aspect of agriculture, aiming to protect crops from harmful organisms that can reduce yield and quality. Conventional methods such as manual scouting and blanket spraying are often inefficient, costly, and environmentally damaging. Therefore, there is a growing need for innovative tools that can enhance pest detection and control while minimizing negative impacts. One such tool is drone technology, which involves the use of unmanned aerial vehicles (UAVs) or remotely piloted aircraft systems (RPAS) for various agricultural purposes. Drones can be equipped with cameras, sensors, and dispensers to collect and analyze data, as well as apply treatments precisely and timely. They offer benefits like improving accuracy, reducing time, saving costs, and increasing sustainability [14].

2.2 Examples of Drone Technology in Agriculture Today

- In California, drones are used to detect citrus greening disease, enabling quick identification and targeted removal of infected trees to prevent disease spread [15].
- In Australia, drones help control the Mediterranean fruit fly by spraying pesticides on fruit trees, reducing infestations and protecting the fruit industry.
- In the United States, drones release beneficial insects like ladybugs to control aphids in pecan trees, offering a natural and effective pest management solution [16].

2.3 How Drones are Important in Pest Management?

Drone technology effectively monitors and controls insect pests in agricultural fields by capturing high-resolution aerial images and using sensors to detect pests. This technology enables precise pesticide application that is environmentally safe, providing farmers with accurate information to take timely actions against infestations [17].

- **Detect Pests Early:** Drones equipped with cameras and sensors can detect pests before they are visible, enabling early intervention.
- **Monitoring of Insect Population:** Drones monitor insect populations, behavior, and spread, aiding in predictive pest management strategies.
- **Precise Pesticide Application:** Drones apply pesticides directly to pests, reducing environmental impact and optimizing effectiveness.
- **Release of Beneficial Insects:** Drones release beneficial insects like ladybugs to control pests naturally, minimizing reliance on pesticides.
- **Reduced Pesticide Use:** Precise application reduces overall pesticide use, mitigating environmental and health risks.
- **Improved Crop Yields:** By preventing and managing pest infestations promptly, drones contribute to higher crop yields.
- **Increased Efficiency and Safety:** Drones streamline pest management operations, saving time and labor while improving safety for operators.
- **Cost Savings:** Automating tasks reduces labor costs associated with traditional pest management methods.

3. INNOVATIONS

3.1 Remote Sensing and Precision Agriculture

Multispectral and Hyperspectral Imaging: Drones equipped with multispectral and hyperspectral cameras can capture images across various wavelengths, providing valuable information on plant health. For instance, healthy plants reflect more near-infrared light compared to stressed or diseased plants, which exhibit different reflection patterns. This technology allows for the early detection of diseases such as powdery mildew and rust. For example, a study by Calderón et al. [18] demonstrated the use of hyperspectral imaging to detect downy mildew in opium poppy fields.

Thermal Imaging: Thermal cameras on drones can detect temperature variations in the crop canopy. Diseased plants often have different temperature profiles due to changes in transpiration and metabolic activity. Early detection of bacterial wilt, for instance, can be achieved through thermal imaging, allowing for the timely removal of infected plants to prevent further spread. Sankaran et al. [19] reviewed the application of thermal imaging for detecting plant diseases.

RGB Imaging: RGB cameras capture high-resolution images in the visible spectrum. These images can be processed to create detailed maps of crop health. Software algorithms can analyze these images to detect symptoms of diseases like leaf spots, blights, and downy mildew. Hunt and Daughtry [20] highlighted the utility of RGB imaging in precision agriculture, noting its effectiveness in monitoring crop health and disease symptoms.

4. DISEASE MAPPING AND MONITORING

Georeferenced Disease Maps: Drones can create georeferenced maps that pinpoint the exact location of disease outbreaks within a field. These maps help farmers and agronomists monitor disease progression and plan targeted interventions. For example, georeferenced maps can show the spread of soybean rust, allowing for precise fungicide application. West et al. [21] discussed how these maps enhance disease management strategies.

Time-Series Analysis: Drones can capture images at regular intervals, enabling time-series analysis of disease development. This approach helps in understanding the dynamics of disease spread and the effectiveness of control measures. Time-series data can be used to predict future outbreaks and optimize disease management strategies. Kamilaris et al. [22] reviewed the use of time-series analysis in studying crop growth and disease progression.

5. PRECISION SPRAYING

Targeted Application: Drones equipped with sprayers can apply pesticides, fungicides, and herbicides precisely where needed. This targeted application reduces chemical use and minimizes environmental impact. For example, drones can be programmed to spray only the areas affected by diseases like late blight in potatoes, reducing overall fungicide usage. Giles and Billing [23] explored the deployment of UAVs for targeted crop spraying, highlighting their efficiency and accuracy.

Variable Rate Application: Drones can vary the rate of application based on the severity of the disease detected in different parts of the field. This ensures that heavily infected areas receive more treatment while less affected areas receive minimal or no treatment, optimizing the use of resources and reducing costs [24-26]. This approach has been demonstrated to improve disease management in vineyards and orchards.

6. DATA INTEGRATION AND ANALYTICS

Integration with GIS and IoT: Drone data can be integrated with Geographic Information Systems (GIS) and Internet of Things (IoT) devices to create comprehensive crop health monitoring systems. For example, combining drone imagery with soil moisture sensors and weather data provides a holistic view of crop health and disease risks. Hunt and Daughtry [20] highlighted the benefits of integrating drone data with other agricultural technologies[27-29].

Machine Learning and AI: Machine learning algorithms can process large volumes of drone data to identify disease patterns and predict outbreaks. AI models can analyze images to classify diseases and assess their severity. This technology is particularly useful for detecting complex diseases that show varied symptoms across different growth stages. Kamilaris et al [22].Reviewed the use of AI in precision agriculture, noting its potential in disease detection and management.

7. CHALLENGES

7.1 Technical Limitations

Battery Life and Flight Time: Drones have limited battery life, which restricts the area they can cover in a single flight. For large farms, multiple flights and frequent battery changes are required, increasing operational complexity and costs. This limitation is a significant challenge for the widespread adoption of drone technology in agriculture.

Image Resolution and Processing: High-resolution images require significant storage and processing power. Managing and analyzing large datasets can be challenging, especially for farmers without access to advanced computing resources. This issue is compounded by the need for real-time data processing for timely decision-making [30-33].

Weather Dependence: Drone operations are highly dependent on weather conditions. High winds, rain, and fog can hinder drone flights and affect the quality of images captured. This limitation can delay disease detection and intervention, impacting the effectiveness of disease management strategies.

8. REGULATORY AND SAFETY CONCERNS

Regulatory Compliance: Operating drones in agricultural settings requires compliance with local aviation regulations. Restrictions on flight altitude, proximity to populated areas, and no-fly zones can limit the use of drones. Obtaining necessary permissions and licenses can be a complex process. Benson [34] discussed the regulatory challenges faced by drone operators in agriculture.

Privacy and Security: The use of drones raises privacy concerns, particularly when operating near residential areas. There is also the risk of data breaches and unauthorized access to sensitive agricultural data, which can pose security threats. These issues must be addressed to ensure the safe and ethical use of drones [35,36].

9. ECONOMIC AND PRACTICAL BARRIERS

Cost of Technology: The initial investment in drone technology, including the cost of drones, cameras, and software, can be high. Small and medium-sized farms may find it challenging to justify these costs without clear economic benefits. Lowenberg-DeBoer and Erickson [37] highlighted the economic barriers to adopting precision agriculture technologies, including drones.

Skill and Training: Effective use of drones requires technical skills and knowledge. Farmers and agronomists need training to operate drones, interpret data, and integrate insights into their disease management practices. Lack of access to training resources can be a significant barrier to adoption.

10. DATA MANAGEMENT AND ANALYSIS

Data Overload: The large volume of data generated by drones can be overwhelming. Efficient data management systems and analytical tools are required to process and extract actionable insights. Without proper data management, the potential benefits of drone technology may not be fully realized.

Interoperability: Integrating drone data with existing farm management systems can be challenging due to compatibility issues. Ensuring that drone data is compatible with various software platforms and IoT devices requires standardized protocols and practices.

11. CONCLUSION

Drone technology holds significant promise for the management of crop diseases, offering innovations in remote sensing, disease mapping, precision spraying, and data analytics. However, several challenges need to be addressed to fully realize its potential. Addressing technical limitations, regulatory and safety concerns, economic barriers, and data management issues will be crucial for the widespread adoption of drones in agriculture. By overcoming these challenges, drone technology can become a vital tool in sustainable and effective crop disease management.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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