

MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
NATIONAL AVIATION UNIVERSITY
FACULTY OF AIR NAVIGATION, ELECTRONICS AND
TELECOMMUNICATIONS
DEPARTMENT OF AVIONICS

APPROVED

Head of the department

_____ Yu. V. Hryshchenko

‘ ___ ’ _____ 2024

QUALIFICATION PAPER

(EXPLANATORY NOTES)

FOR THE DEGREE OF «BACHELOR»

SPECIALITY 173 ‘AVIONICS’

**Theme: Application of drones in modern
agriculture**

Done by: Du Shangjun

Supervisor: _____

Standard controller: _____

Kyiv 2024

Abstract

With the increasing requirements of modern agriculture for precision and intelligence, the application of UAV technology in the agricultural field is becoming more and more extensive. This paper first introduces the development history of UAV technology and its application background in modern agriculture, and analyzes the basic composition and key technologies of UAV systems. Then, this paper discusses in detail the application of UAVs in agricultural monitoring, precision agriculture, and agricultural disaster prevention and rescue, and studies key technologies such as UAV flight control, agricultural information acquisition and processing, and UAV payload for these application scenarios. In addition, this paper also evaluates the application effect of UAV technology in agriculture through case analysis of domestic and foreign UAV agricultural applications, and points out the problems and challenges in current applications. Finally, this paper looks forward to the future development trend of UAV technology in the agricultural field and puts forward corresponding policy and regulatory recommendations. The research in this paper has important theoretical and practical significance for promoting the application of UAV technology in modern agriculture.

Keywords: UAV; modern agriculture; precision agriculture; agricultural monitoring; agricultural disaster prevention

Анотація

Оскільки вимоги сучасного сільського господарства до точності та інтелекту продовжують зростати, технологія безпілотників все частіше використовується в сільському господарстві. Ця стаття спочатку знайомить з історією розвитку технології безпілотних літальних апаратів та передумовами їх застосування в сучасному сільському господарстві, а також аналізує основні компоненти та ключові технології системи безпілотних літальних апаратів. Далі в цій статті детально розглядається застосування дронів у сільськогосподарському моніторингу, точному землеробстві та запобіганні аварійним ситуаціям у сільському господарстві. Для цих сценаріїв розглядається управління польотом дронів, збір і обробка сільськогосподарської інформації, а також інші ключові технології. Крім того, у цій статті також оцінюється ефект застосування безпілотних літальних апаратів у сільському господарстві за допомогою аналізу вітчизняних і зарубіжних сільськогосподарських застосувань безпілотних літальних апаратів і вказується на проблеми та виклики, які існують у поточному застосуванні. Нарешті, у цій статті розглядаються майбутні тенденції розвитку безпілотних літальних апаратів у галузі сільського господарства та висувуються відповідні політичні та нормативні пропозиції. Дослідження в цій статті має важливе теоретичне та практичне значення для просування застосування безпілотних технологій у сучасному сільському господарстві.

Ключові слова: сучасне сільське господарство, попередження сільськогосподарських катастроф

Literature Review

The application of UAV technology in modern agriculture has become a hot topic of research at home and abroad. With the continuous advancement of UAV technology, its application potential in the agricultural field is becoming increasingly apparent. UAVs have the advantages of high maneuverability, low cost and flexible deployment, which can effectively improve agricultural production efficiency, reduce labor intensity and realize precision agricultural management. Domestic and foreign studies have shown that the application of UAVs in agricultural monitoring and information acquisition, precision agriculture, agricultural disaster prevention and rescue has achieved remarkable results. Especially in crop growth monitoring, soil moisture and nutrition monitoring, pest and disease monitoring, etc., the high-resolution cameras and sensors carried by UAVs can provide real-time and accurate data support. In addition, the application of UAVs in precision fertilization, pesticide application and irrigation, as well as the practice in the delivery of emergency rescue materials, post-disaster assessment and reconstruction, also show its important role in agricultural production.

At present, key technologies for the application of UAVs in agriculture, such as flight control, navigation positioning, image processing and recognition, have made great progress. Domestic and

foreign scholars and research institutions have conducted extensive research on the application of UAVs in agriculture, including the stability of flight control technology, autonomous flight path planning, flight safety and obstacle avoidance. At the same time, the improvement of agricultural information acquisition and processing technology, such as high-resolution image acquisition, data fusion and analysis, and crop identification and classification, has provided strong support for precision agriculture. The research and development of payload technology, such as pesticide spraying and seed sowing, is also being optimized to meet the needs of different agricultural production.

There have been some successful cases of drone agricultural applications at home and abroad, such as the United States' PrecisionHawk company has achieved remarkable results in agricultural monitoring and analysis, and China's XAG has also achieved commercial success in the field of plant protection drones. These cases show that drones have great potential in improving agricultural production efficiency, saving resources, and protecting the environment. However, the application of drones in agriculture still faces some challenges, such as technical difficulties, insufficient policy and regulatory support, and market promotion, which require further research and practice to solve.

In summary, the application prospects of drone technology in modern agriculture are broad, but it is still necessary to continuously break through technical bottlenecks, improve relevant policies and regulations, and strengthen market promotion to achieve the widespread application and sustainable development of drones in the agricultural field. With the continuous advancement of technology and the accumulation of application experience, drones are expected to become an important tool for future agricultural development.

Chapter One Introduction

1.1 Research background and significance

1.1.1 Current status of modern agricultural development

Modern agriculture is undergoing an unprecedented technological revolution, with intelligence, precision and sustainability becoming the main trends in its development. With the growth of the global population and the increase in resource pressure, agricultural production needs to be more efficient and environmentally friendly. Modern agriculture has achieved precise management of soil, crops and water resources by adopting advanced agricultural technologies such as precision agriculture, intelligent irrigation systems, remote sensing monitoring, etc. In addition, the application of biotechnology, such as genetically modified crops and microbial fertilizers, has also played an important role in improving crop yields and quality. However, the development of modern agriculture also faces challenges, including environmental pollution, reduced biodiversity, and food safety issues. Therefore, the development of agriculture in the future needs to pay more attention to ecological balance and sustainability to ensure long-term food security and ecological health for mankind.

1.1.2 Development of UAV Technology

Since its birth in the early 20th century, drone technology has undergone a major transformation from simple remote-controlled aircraft to modern high-tech unmanned aerial vehicles. At first, drones were mainly used for military

reconnaissance and strike missions, but with the advancement of technology, their application areas have continued to expand, especially in the civilian field. Drones have become a powerful tool for many industries such as agriculture, surveying and mapping, film and television production, logistics and transportation.

The development of drone technology is mainly reflected in the following aspects:

1. Improvement of automation and intelligence. Early drones required manual control, but now drones can achieve autonomous takeoff, flight, mission execution and return, thanks to advanced flight control systems and intelligent algorithms.

2. Advances in sensor and payload technology. Modern drones are equipped with high-resolution cameras, multi-spectral sensors, lidar, etc., which can collect more accurate data information and provide strong support for agriculture, environmental monitoring and other fields.

3. Innovation in communication and navigation technology. Drones achieve precise positioning and long-distance communication through the support of multiple satellite navigation systems such as GPS, GLONASS, Beidou and ground stations, greatly improving operating efficiency and safety.

4. Optimization of energy and power systems. The endurance of drones is constantly improving with the advancement of battery technology. At the same time, the development of new energy drones such as solar drones and hydrogen fuel drones also provides the possibility for the long-term stable operation of

drone technology.

As technology continues to mature and costs gradually decrease, drones will play a greater role in the future and become an indispensable part of people's lives.

1.1.3 Necessity of using drones in agriculture

With the development of modern agriculture, drone technology has gradually become an important tool in agricultural production with its unique advantages. First of all, drones can achieve efficient acquisition of farmland information. By carrying various sensors, they can monitor key information such as crop growth conditions, soil moisture, and the occurrence of pests and diseases in real time, providing data support for precision agriculture. Secondly, drones show significant advantages in operations such as pesticide application and fertilization. Compared with traditional operation methods, drones have high operation efficiency and uniform coverage, which can greatly reduce the use of pesticides and fertilizers and reduce environmental pollution. In addition, drones play an important role in disaster prevention and emergency rescue. They can quickly carry out assessments after disasters, deliver materials in a timely manner, and improve rescue efficiency. Therefore, the application of drones in agriculture not only improves agricultural production efficiency, but also helps to achieve green and sustainable development.

1.2 Current research status at home and abroad

1.2.1 Foreign research on agricultural applications of

drones

Foreign research on the application of drones in agriculture began in the early 21st century, with countries such as the United States, Israel and Japan leading in this field. The U.S. Department of Agriculture began using drones for crop monitoring and evaluation in the early days, and analyzed crop growth conditions through high-resolution images. Israel has continuously innovated in drone agricultural application technology, developed precision irrigation and fertilization systems, and achieved optimal resource allocation through drones. Japan has achieved remarkable results in drone plant protection operations, using drones for pesticide spraying to improve operational efficiency and safety. In addition, many European countries are also actively exploring the application of drones in agriculture, especially in crop pest and disease monitoring and geographic information system (GIS) data collection, showing great potential. The experience of these countries provides a valuable reference for the development of global drone agricultural technology.

1.2.2 Research on the Application of UAVs in Agriculture in China

In the past decade, with the continuous maturity of drone technology and the reduction of costs, China's agricultural drone industry has developed rapidly. Domestic research on drone agricultural applications mainly focuses on the following aspects:

First, precision agriculture is one of the research hotspots. By carrying high-

resolution cameras and multispectral sensors, drones can collect detailed crop growth information and provide data support for precision fertilization and precision spraying. These technologies help improve agricultural production efficiency, reduce the use of chemical pesticides, and reduce environmental pollution.

Secondly, disaster monitoring and emergency response are also research focuses. Drones can be quickly deployed to monitor the impact of natural disasters such as floods and droughts on crops, and conduct rapid assessments after disasters occur, providing decision support for rescue and post-disaster reconstruction.

In addition, the application of drones in pest and disease monitoring and prevention is also an important research area. Through regular aerial inspections, drones can promptly detect early signs of pests and diseases, thereby carrying out targeted prevention and control and effectively controlling the spread of pests and diseases.

In terms of research methods, domestic scholars not only focus on technical innovations, such as improving the stability and endurance of drone platforms, but also focus on deep integration with the agricultural field, such as developing dedicated sensors and data analysis models for different crops.

Although domestic research on the application of drones in agriculture has made some progress, it still faces problems in actual promotion, such as insufficient data processing capabilities, lack of farmers' operating skills, and

imperfect policies and regulations. Therefore, future research needs to pay more attention to problems in practical applications, strengthen interdisciplinary cooperation, and promote the widespread application of drone technology in the agricultural field.

1.2.3 Challenges in UAV agricultural application research

The application of drones in the agricultural field is gradually expanding, but it still faces many challenges. The first is the technical difficulties, including the stability and accuracy of the flight control system, and the processing and analysis technology of aerial image data. The autonomous navigation ability of drones in complex agricultural environments and their adaptability to various climatic conditions still need to be further improved.

Secondly, the economic benefit analysis of drone agricultural applications is also a major challenge. Although drones can improve operational efficiency, their purchase and maintenance costs are relatively high, which may be difficult for small farmers to afford. In addition, the comparative analysis of the cost-effectiveness of drone operations and traditional agricultural operations is also an issue that needs in-depth research.

Finally, there are also challenges in policies and regulations. The large-scale application of drones in the agricultural field involves issues such as airspace management and data privacy protection. At present, relevant laws and regulations are not yet perfect, which has imposed certain restrictions on the

promotion and application of drones. Therefore, formulating reasonable policies and regulations to regulate the use of drones in the agricultural field is the key to promoting their development.

1.3 Research content and methods

1.3.1 Research content of the paper

This chapter mainly discusses the application of drones in modern agriculture. It first introduces the origin, development history and current classification of drone technology, and conducts an in-depth analysis of the key technologies of drones. Subsequently, the specific applications of drones in the agricultural field are discussed in detail, including agricultural monitoring, precision agriculture, and disaster prevention and rescue. In addition, this chapter also studies the key technologies of drones in agricultural applications, such as flight control technology, agricultural information acquisition and processing technology, and drone payload technology. Finally, through the analysis of domestic and foreign drone agricultural application cases, the application effect of drones in agriculture is evaluated, and the current problems and corresponding improvement measures are pointed out.

1.3.2 Research methods and technical routes

When studying the application of drones in modern agriculture, this chapter adopts a series of scientific research methods and technical routes to ensure the systematicness and reliability of the research. First, through the literature review method, the literature on the application of drones in agriculture at home and

abroad is widely collected and analyzed to provide a theoretical basis and empirical reference for the research. Secondly, the field investigation method is adopted to go deep into the agricultural production site to observe and record the application of drones in crop monitoring, pest control, precision fertilization, etc., and collect first-hand data. Then, through the case analysis method, typical drone agricultural application cases are selected for in-depth analysis to explore their application effects and existing problems. Finally, the experimental research method is used to design and implement experiments on the application of drones in agriculture, and the actual effects and economic benefits of drone applications are verified through comparative experiments and data analysis. Throughout the research process, emphasis is placed on the combination of theory and practice, and efforts are made to make the research practical and innovative.

1.3.3 Paper Organization

This paper is divided into six chapters, and the contents of each chapter are arranged as follows: Chapter 1 is an introduction, which explains the research background, significance and current research status at home and abroad, and introduces the research content and methods. Chapter 2 is an overview of UAV technology, which details the development history, system composition and key technologies of UAVs. Chapter 3 discusses the application of UAVs in modern agriculture, including agricultural monitoring, precision agriculture and disaster prevention. Chapter 4 conducts an in-depth study of the key technologies of UAV

agricultural applications, such as flight control, information acquisition and processing, and payload technology. Chapter 5 analyzes multiple UAV agricultural application cases and evaluates the application effects. The last chapter summarizes the research results of the whole article, points out the research deficiencies, and looks forward to future research directions and policy and regulatory recommendations.

Chapter 2 Overview of UAV Technology

2.1 Development History of UAVs

2.1.1 Origin of UAVs

As an unmanned aerial vehicle, drones originated in the early 20th century, and their initial form can be traced back to 1907, when Nicholas Spera first proposed the concept of radio-controlled aircraft. However, it was not until World War I that the military potential of drones began to emerge. At that time, drones were mainly used as target practice to train anti-aircraft gunners. These early drones were usually simple aircraft controlled by radio, and their design and manufacturing technology was relatively primitive.

As electronic technology and communication technology developed, drones gradually became more complex and operational. During World War II, drones were used to perform more dangerous tasks, such as reconnaissance and attack. For example, the US Navy used radio-controlled aircraft called "target planes" for air defense training, while Germany developed the V-1 flying bomb, an early unmanned attack weapon.

During the Cold War, the use of unmanned reconnaissance aircraft became more common, especially for intelligence gathering in high-risk areas. The Central Intelligence Agency (CIA) used a series of drones called "AQM-34" for high-altitude reconnaissance missions, marking the further development of drone technology in the military field.

As drone technology continued to advance over time, their application areas also expanded. From the initial military use, drones have gradually been applied to civilian fields such as agriculture, film production, geographic surveying and environmental protection. Today, drones have become an important part of modern technology, and their application in various industries is becoming more and more extensive and in-depth.

2.1.2 Evolution of UAV Technology

Since its birth, drone technology has evolved from simple remote-controlled aircraft to highly intelligent unmanned aerial systems. This process can be divided into several key stages:

1. Initial stage: In the early 20th century, drone technology originated from military reconnaissance and target drone needs. Early drones mainly relied on simple radio remote control systems, had limited flight range, and lacked autonomy.

2. Development stage: In the mid-20th century, with the development of electronic technology, drones began to be equipped with more complex navigation and control systems. Drones of this period were able to perform more

complex tasks, such as high-altitude reconnaissance and electronic interference.

3. Mature stage: From the late 20th century to the early 21st century, with the rapid development of computer technology, communication technology, and sensor technology, drone technology entered a mature stage. The autonomous navigation, target recognition, and real-time data processing capabilities of drones have been significantly improved, making their application in the civilian field, especially in modern agriculture, possible.

4. Intelligent stage: After entering the 21st century, drone technology has further integrated technologies such as artificial intelligence, machine learning, and big data analysis, making its application in agricultural monitoring, crop management, disaster assessment, etc. more accurate and efficient. The autonomous flight capability, mission execution capability and data processing capability of drones have reached new heights, providing strong technical support for the development of modern agriculture.

2.1.3 Classification of UAVs

UAVs are classified based on their design features, purpose, flight capabilities, and operation methods. Here are some common classifications of UAVs:

Fixed-wing UAVs: These drones have wings that can generate reverse thrust in the air, allowing them to fly steadily for a long time. They are often used for long-distance monitoring and reconnaissance missions, but require a runway or catapult to take off and glide when landing.

Multicopter UAVs: Multicopter UAVs usually have three or more propellers and

can take off and land vertically (VTOL), making them ideal for operating in tight spaces and performing precise hovering tasks. They are mainly used in agriculture for crop monitoring and pesticide spraying.

Single-rotor UAVs: These drones have a main rotor and a tail rotor, similar to helicopters. They are also able to take off and land vertically, and single-rotor UAVs usually have longer flight times and better flight performance than multi-rotor UAVs.

Unmanned airships: Unmanned airships are lifted into the air by the buoyancy of internal gases and are usually used for long-term air stays and advertising. In the agricultural field, they can be used for large-area monitoring tasks.

Underwater drones: Although primarily used for ocean exploration and monitoring, underwater drones can also be used to monitor aquaculture environments and resources.

There are many different types of drones, each with its own specific advantages and application scenarios. In modern agriculture, multi-rotor drones are widely used due to their flexibility and precision. With the continuous advancement of technology, the classification and application of drones will become more diversified.

2.2 UAV system components

2.2.1 Flight platform

One of the core components of a UAV system is the flight platform, which is the carrier of all other systems and equipment. The design and performance of

the flight platform directly affect the overall performance and application scope of the UAV. The following is a detailed description of the flight platform:

The flight platform is the physical basis of the UAV system, which includes components such as the fuselage, power system, transmission system and landing gear. Designing an efficient and stable flight platform is crucial to ensuring the reliability and mission execution capability of the UAV.

2.2.1.1 Fuselage structure

The fuselage is the skeleton of the UAV, and its design needs to take into account strength, stiffness, weight and aerodynamic characteristics. The choice of fuselage materials, such as carbon fiber, glass fiber or aluminum alloy, has an important impact on the performance and cost of the UAV.

2.2.1.2 Power system

The power system is the "heart" of the UAV, which provides the UAV with the thrust required for flight. The power system usually includes an engine (or motor) and a corresponding fuel or power system. Choosing a suitable power system is crucial to ensuring the endurance and flight speed of the UAV.

2.2.1.3 Transmission system

The transmission system is a bridge connecting the power system and the propulsion device, which transmits the power of the engine to the propeller or other propulsion equipment. The efficiency and reliability of the transmission system directly affect the performance and stability of the UAV.

2.2.1.4 Landing gear

The landing gear is designed to protect the safety of the UAV during takeoff and landing. The type and structure of the landing gear will vary depending on the purpose of the drone and the operating environment.

In summary, the design and optimization of the flight platform is an important area of research in drone technology. Through the careful design of the fuselage structure, power system, transmission system and landing gear, the flight performance and mission execution capabilities of the drone can be improved, thereby meeting the growing demand for drones in modern agriculture and other fields.

2.2.2 Flight Control System

The flight control system is the core component of the UAV, responsible for executing flight instructions and ensuring that the UAV can fly stably according to the predetermined trajectory. It mainly includes flight control board, sensors, actuators and software algorithms. The flight control board is the control center of the system. It calculates the flight status of the UAV in real time by receiving data from sensors such as the global positioning system (GPS), inertial measurement unit (IMU), and barometer. The actuators include motors, servos and propellers, which adjust the power output according to the instructions issued by the control board to achieve the lifting, forward, backward and steering of the UAV. The software algorithm is the "brain" of the control system. Through complex mathematical models and control strategies such as PID control and fuzzy control, it processes sensor data and generates control instructions to

ensure the stability and accuracy of the UAV under various flight conditions. With the development of technology, the flight control system is moving towards intelligence and autonomy to adapt to more complex flight tasks and environments.

2.2.3 Mission payload system

In the UAV system, the mission payload system is a key component for performing specific tasks, which is directly related to the application effect of UAVs in the agricultural field. The mission payload system usually includes sensors, cameras, sprayers and other equipment, which are responsible for collecting data, monitoring crop growth, and implementing precision operations.

Sensors are an important part of the mission payload system. They can collect various environmental data, such as soil moisture, temperature, crop health, etc. These data are crucial to achieving precision agriculture. By analyzing these data, farmers can understand the growth status of crops in a timely manner and take corresponding management measures.

Cameras play a monitoring and analysis role in drone agricultural applications. By carrying high-resolution cameras, drones can capture clear crop images, which can be used to analyze crop growth conditions, pest and disease occurrence, etc. In addition, multispectral cameras can also provide more dimensional data to help farmers better understand crop health.

Sprayers are the main tools for drones to carry out plant protection operations in agriculture. It can accurately control the spraying amount and spraying position

of pesticides to achieve precise application of pesticides, which not only improves the utilization rate of pesticides, reduces pesticide waste, but also reduces the risk of environmental pollution.

In addition to the above equipment, the mission payload system can also carry other types of equipment according to different agricultural needs, such as seed spreaders, fertilizer spreaders, etc., to achieve more agricultural operation functions.

In short, the design and configuration of the mission payload system directly affects the application effect of UAVs in the agricultural field. An efficient mission payload system can help farmers improve production efficiency, reduce resource waste, and achieve sustainable agricultural development.

2.3 Key technologies of UAVs

2.3.1 Flight control technology

Flight control technology is a crucial part of the UAV system, which ensures the stable flight and precise operation of the UAV. The core of this technology lies in the design of the flight control system, which includes key components such as sensors, controllers and actuators.

First, the sensor is responsible for collecting flight data, such as acceleration, attitude, position and speed, which are the basis of flight control. The controller calculates the control instructions based on these data and the preset flight plan. Actuators such as motors and servos adjust the flight state of the UAV according to the control instructions to achieve flight control.

In order to improve flight control performance, modern UAVs generally use advanced control algorithms, such as PID (proportional-integral-differential) control, fuzzy control and neural network control. These algorithms can quickly respond to disturbances in flight and maintain the stable flight of the UAV.

In addition, autonomous flight path planning technology is also closely related to flight control. It plans the optimal flight path through real-time analysis of environmental information to ensure that the UAV can complete its tasks safely and effectively in a complex flight environment.

The development of flight control technology has also promoted the application of UAVs in agriculture, such as precision pesticide application and crop monitoring. By precisely controlling the position and attitude of the drone, efficient agricultural operations can be achieved, crop yields and quality can be improved, and pesticide pollution to the environment can be reduced.

In short, flight control technology is the core of drone system design and application. It is not only related to the stability and safety of drones, but also the key to the application of drones in agriculture and other fields. With the continuous advancement of technology, drones in the future will be more intelligent and efficient, bringing more possibilities to modern agriculture.

2.3.2 Navigation and positioning technology

In modern agriculture, the development of drone technology has brought revolutionary changes to agricultural production. Drones are equipped with advanced navigation and positioning technology, making agricultural operations

more accurate and efficient. Navigation and positioning technology is one of the key technologies for the application of drones in the agricultural field. It ensures that drones can accurately perform tasks and improves operation efficiency and accuracy.

Navigation and positioning technology mainly includes global positioning system (GPS), inertial navigation system (INS), visual navigation and multi-sensor fusion technology. GPS is the most commonly used navigation and positioning technology. It determines the precise position of the drone by receiving signals from satellites. The inertial navigation system calculates the position and direction by measuring the acceleration and angular velocity of the drone. It is not affected by external electromagnetic interference and can continue to work when the GPS signal is interfered with or cannot be received. Visual navigation captures ground image information through a camera and combines image processing algorithms to determine the flight position and path of the drone. Multi-sensor fusion technology combines multiple technologies such as GPS, INS, and visual navigation to improve the accuracy and reliability of navigation and positioning.

In agricultural applications, the accuracy of navigation and positioning technology directly affects the effect of drone operations. For example, when monitoring crops, drones need to accurately fly over each field to obtain comprehensive crop growth information. When applying pesticides with precision, drones need to fly accurately along the predetermined route to ensure that pesticides can be sprayed accurately where needed. In addition, navigation and

positioning technology can also help drones maintain stable flight in bad weather or complex terrain, improving the safety of operations.

In short, navigation and positioning technology is one of the core technologies for the application of drones in modern agriculture, which has brought unprecedented convenience and efficiency to agricultural production. With the continuous advancement of technology, the navigation and positioning technology of drones in the future will be more accurate and reliable, making greater contributions to the sustainable development of agriculture.

2.3.3 Image processing and recognition technology

Image processing and recognition technology is one of the key technologies for the application of drones in modern agriculture. It captures the image data of farmland and uses image processing algorithms to analyze and process the data, thereby accurately identifying information such as crop growth conditions and the occurrence of pests and diseases. This process not only improves the level of intelligence in agricultural production, but also provides technical support for the implementation of precision agriculture.

In specific applications, image processing and recognition technology mainly includes the following steps:

First, image acquisition. The high-resolution camera carried by the drone can obtain detailed images of farmland from the air. These images have a wide coverage and high resolution, and can clearly reflect the actual situation of the farmland.

Second, image preprocessing. In order to improve the accuracy of subsequent analysis, the collected images need to be preprocessed. This includes steps such as image denoising, enhancement, and geometric correction to remove interference factors in the image and improve image quality.

Next, feature extraction. Through image processing algorithms, key features such as color, texture, shape, etc. are extracted from the preprocessed images. These features are the basis for identifying crop growth conditions and pests and diseases.

Then, image recognition. Based on the extracted features, machine learning or deep learning algorithms are used to classify and identify images to determine the growth stage of crops, types of pests and diseases, etc.

Finally, decision support. Combine the recognition results with the knowledge of agricultural experts to provide decision support for farmers and guide farmers to conduct reasonable agricultural production management.

The application of image processing and recognition technology has greatly improved the efficiency and quality of agricultural production, and is of great significance to promoting the development of modern agriculture. With the continuous advancement of technology, this technology will play a greater role in the agricultural field in the future.

Chapter 3 Application of drones in modern agriculture

3.1 Agricultural monitoring and information

acquisition

3.1.1 Crop growth monitoring

With the continuous advancement of agricultural production technology, crop growth monitoring has become an important part of modern agricultural management. As an efficient monitoring tool, drones play an increasingly important role in crop growth monitoring due to their flexibility and adaptability.

First, the aerial photography capability of drones enables them to obtain high-resolution images and multispectral data from the air without interfering with crop growth. These data can accurately reflect the state of crop growth, including leaf area index, vegetation coverage, crop health, etc. By analyzing these data, agricultural experts can promptly discover problems in crop growth, such as malnutrition, pests and diseases, and take corresponding management measures.

Second, the real-time nature of drone monitoring is unmatched by traditional ground monitoring. During the critical period of crop growth, such as sowing, irrigation, fertilization and before harvest, drones can quickly cover large areas of fields, provide timely growth information for crops, and help farmers make reasonable planting decisions.

Finally, the cost-effectiveness of drone monitoring is more advantageous than traditional monitoring methods. With the maturity of technology and the popularization of equipment, the price of drones has gradually become affordable, making it affordable even for small-scale farmers. At the same time, drone monitoring reduces labor costs and time and improves agricultural production

efficiency.

In summary, the application of UAVs in crop growth monitoring not only improves the accuracy and timeliness of monitoring, but also reduces costs, providing strong technical support for the development of modern agriculture.

3.1.2 Soil moisture and nutrition monitoring

In modern agriculture, soil moisture and nutrition monitoring is an important aspect of drone applications. By carrying high-resolution sensors and cameras, drones can quickly and accurately obtain soil moisture and nutrition information over a large area. The advantage of this monitoring method is its high efficiency and low cost, which can help farmers understand the soil conditions in a timely manner, so as to carry out precise irrigation and fertilization, and improve agricultural production efficiency and resource utilization.

Drone soil moisture monitoring usually uses infrared thermal imaging technology to infer the distribution of soil moisture by analyzing the difference in surface temperature. The soil temperature in arid areas is usually higher than that in humid areas because water can absorb more solar radiation energy. By analyzing thermal imaging data, a soil moisture distribution map can be generated to guide farmers to carry out regional irrigation and avoid excessive or insufficient water supply.

In terms of nutrition monitoring, drones can be equipped with multispectral or hyperspectral cameras to evaluate the nutrient content of the soil by analyzing the reflectivity of different bands. For example, by measuring the reflectivity of red

light and near-infrared light absorbed by chlorophyll, the nitrogen nutrition status of the plant can be inferred. This technology can not only detect the nutritional status of the plant surface, but also evaluate the overall health of the plant through vegetation indexes (such as NDVI).

Using drones to monitor soil moisture and nutrition can not only improve the real-time and accuracy of monitoring, but also reduce labor costs and environmental impact. Through the analysis of monitoring data, farmers can make agricultural management decisions more scientifically, realize the rational allocation and utilization of resources, and thus improve the yield and quality of crops. With the development of technology, the application of drones in soil monitoring will be more extensive, providing strong technical support for the sustainable development of modern agriculture.

3.1.3 Pest and disease monitoring

With the development of modern agriculture, the monitoring of pests and diseases has become particularly important. The application of drone technology provides a new means for pest and disease monitoring, which can quickly and accurately identify and analyze the occurrence and development of pests and diseases. By carrying high-resolution cameras, multispectral or hyperspectral sensors and other equipment, drones can monitor crops on a large scale, detect early signs of pests and diseases in a timely manner, and take corresponding prevention and control measures.

The application of drones in pest and disease monitoring mainly includes the

following aspects:

1. Early warning: drones can effectively cover large areas of farmland. Through regular flight monitoring, they can timely detect the early symptoms of pests and diseases and provide early warning information for pest and disease prevention and control.

2. Accurate positioning: The sensors and cameras carried by drones can accurately locate the areas where pests and diseases occur, providing a basis for accurate prevention and control of pests and diseases.

3. Dynamic monitoring: drones can continuously monitor the development process of pests and diseases, track the changing trends of pests and diseases in real time, and provide decision-making support for agricultural producers.

4. Data analysis: The data collected by drones can be analyzed through image processing and data analysis software to help agricultural technicians better understand the occurrence of pests and diseases and guide the prevention and control of pests and diseases.

Through drone pest and disease monitoring technology, the effect of pest and disease management can be effectively improved, the use of pesticides can be reduced, environmental pollution can be reduced, and the yield and quality of crops can be increased, promoting the sustainable development of agriculture.

3.2 Precision Agriculture

3.2.1 Precision Fertilization

Precision fertilization is an efficient agricultural management method

implemented using drone technology. It aims to accurately place fertilizers according to the actual needs of crops to improve fertilizer utilization and reduce environmental pollution. The sensors and intelligent fertilization system carried by drones can realize real-time monitoring of crop growth, and intelligently calculate the best time and amount of fertilization based on crop growth conditions and soil fertility. This method can not only improve crop yield and quality, but also effectively reduce the cost and environmental impact of agricultural production. It is an important means for the sustainable development of modern agriculture.

3.2.2 Precision Application of Pesticides

Precision application of pesticides is an important link in realizing intelligent and precise application of pesticides in agricultural production using drone technology. It uses a spraying system on the drone, combined with the actual situation of the farmland and the growth status of the crop, to intelligently control the type, time and amount of pesticide application to achieve the goals of high efficiency, environmental protection and energy saving.

The UAV precision pesticide application system usually includes the following key components:

1. Spraying device: including nozzles, liquid tanks, pressure regulation systems, etc. These devices can automatically adjust the spraying angle and atomization degree according to the growth height and density of crops.

2. Intelligent control system: Through GPS positioning and track planning, the drone can accurately fly over the area where pesticides need to be applied, and

automatically adjust the amount of pesticides applied according to the crop type and growth stage.

3. Liquid management system: responsible for monitoring and controlling the concentration, pressure and flow of the liquid to ensure the uniformity and accuracy of the application.

The advantages of precision pesticide application are:

1. Improve efficiency: UAVs can cover a large area of farmland in a short time, reducing the time and labor cost of manual pesticide application.

2. Reduce the use of pesticides: By accurately controlling the amount of pesticides applied, unnecessary use of pesticides can be reduced and chemical pollution in agricultural production can be reduced.

3. Improve crop safety: UAV pesticide application can avoid direct contact between pesticides and the ground, reduce pollution to soil and groundwater, and ensure the food safety of crops.

4. Improve the prevention and control effect: In response to the occurrence of pests and diseases, drones can apply pesticides in a timely and accurate manner to improve the prevention and control effect.

With the continuous advancement of technology, drone precision spraying systems will become more intelligent, not only to achieve more precise spraying control, but also to achieve real-time analysis and processing of farmland data through the combination with big data, cloud computing and other technologies, and further improve the level of intelligence in agricultural production.

3.2.3 Precision irrigation

As an efficient water-saving technology in modern agriculture, precision irrigation has achieved intelligent and precise irrigation operations through the integration of drone technology. The sensors carried by drones can monitor soil moisture and crop water requirements in real time, and accurately calculate irrigation requirements through data analysis, effectively avoiding the waste of water resources. In addition, drone spraying systems can achieve differentiated irrigation in different regions according to crop growth conditions and terrain characteristics, and improve water utilization efficiency. In practical applications, precision irrigation not only saves water resources and reduces irrigation costs, but also increases crop yield and quality, which is of great significance to promoting sustainable agricultural development.

3.3 Agricultural disaster prevention and rescue

3.3.1 Agricultural disaster monitoring

With the intensification of climate change, agricultural disasters such as drought, floods, pests and diseases are posing an increasingly severe threat to agricultural production. As an efficient and flexible monitoring tool, drones play an important role in agricultural disaster monitoring. Equipped with high-resolution cameras, multispectral sensors and other equipment, drones can quickly obtain detailed information on disaster-affected areas and provide real-time data support for disaster assessment and emergency response.

The advantages of drone monitoring are its high mobility and low cost.

Compared with traditional satellite remote sensing or ground monitoring, drones can more flexibly adjust flight altitudes and paths to adapt to different terrains and disaster characteristics. In addition, drones can be deployed quickly after a disaster occurs, quickly obtain disaster conditions, and provide accurate information for rescue and post-disaster reconstruction.

In practical applications, drone monitoring systems usually combine geographic information systems (GIS) and remote sensing technology to process and analyze the collected data to generate disaster impact assessment reports. These reports include not only the direct impact of the disaster, such as the area of crop damage and the number of farmers affected, but may also include the potential impact of the disaster, such as the spread trend of pests and diseases, soil erosion, etc.

In short, the application of drones in agricultural disaster monitoring not only improves monitoring efficiency, but also enhances the scientificity and accuracy of disaster management, which is of great significance for ensuring agricultural production safety and promoting sustainable agricultural development.

3.3.2 Emergency rescue material delivery

In modern agriculture, the application of drone technology is gradually expanding to the field of emergency rescue, especially when disasters occur, it can quickly and effectively deliver materials to ensure that the affected farmland is rescued in time. This section will discuss in detail the emergency rescue material delivery technology of drones in agricultural disasters and its actual application.

First, the drone emergency rescue material delivery system can quickly respond

to farmland disasters such as floods, droughts, pests and diseases by carrying various payloads such as seeds, pesticides, fertilizers, etc. The system has high mobility and flexibility, can cover a large area of farmland in a short time, carry out accurate material delivery, and significantly improve rescue efficiency.

Secondly, the accuracy of drone rescue material delivery benefits from advanced navigation and positioning technologies such as GPS and GLONASS. These technologies can ensure that drones accurately fly to the predetermined delivery point, reduce material waste, and improve rescue effectiveness. In addition, drones can also carry high-definition cameras to monitor farmland conditions in real time and provide accurate information for rescue decisions.

Finally, the practical application of drone emergency rescue material delivery has achieved remarkable results. In many countries and regions, drones have been used to respond to farmland disasters. For example, after the typhoon disaster in Japan, drones quickly supplied seeds and fertilizers to help crops resume growth. In China, drones delivered pesticides and seeds after flood disasters, effectively preventing the spread of post-disaster pests and diseases.

In summary, the application of drones in the delivery of agricultural emergency rescue materials not only improves the rescue efficiency, but also ensures the accuracy of material delivery, providing a new solution for the rapid response and effective handling of farmland disasters. With the continuous advancement of technology, the role of drones in agricultural emergency rescue will become more important in the future.

3.3.3 Post-disaster assessment and reconstruction

The application of drones in post-disaster assessment and reconstruction is an important technology in modern agriculture. Drones play a key role in the post-disaster assessment stage with their fast, flexible and cost-effective characteristics. Equipped with high-resolution cameras and multispectral sensors, drones can quickly cover large areas of disaster-stricken areas, obtain disaster information, and provide accurate decision-making basis for post-disaster reconstruction.

During the post-disaster assessment phase, drones can quickly determine the extent of the disaster, including crop damage, infrastructure damage, and ecological and environmental changes. Images taken by drones can quickly identify areas that need to be prioritized, providing rescue teams with accurate disaster maps. In addition, drones can monitor the moisture conditions in the disaster area through thermal imaging technology to help assess the survival rate and recovery potential of crops.

During the reconstruction phase, drones also play an indispensable role. Through regular aerial monitoring, the progress of post-disaster recovery can be tracked to ensure the effectiveness of reconstruction work. Drones can also be used to monitor the growth of crops and promptly detect and deal with possible problems, such as the outbreak of pests and diseases or uneven crop growth. In addition, the use of drones in agricultural operations such as sowing, fertilizing, and spraying pesticides can also help speed up the recovery of agricultural production after disasters.

In short, the use of drones in post-disaster assessment and reconstruction not only improves the efficiency and accuracy of post-disaster response, but also provides strong technical support for the rapid recovery of agricultural production in disaster areas. With the continuous advancement of drone technology and the expansion of its application scope, its role in agricultural post-disaster management will become increasingly important.

Chapter 4 Research on Key Technologies for UAV Agricultural Applications

4.1 UAV Flight Control Technology

4.1.1 Flight Stability Control

In modern agriculture, the application of UAV technology is gradually becoming a key means to improve production efficiency and operation quality. In order to ensure that UAVs can fly stably and achieve precise operations in complex and changeable agricultural environments, flight stability control technology is particularly important. This section will discuss in detail the key technologies of UAV flight stability control and analyze its importance in agricultural applications.

First, UAVs often need to fly at low altitudes in agricultural operations. The airflow in this area is relatively complex, and changes in wind speed and wind direction will affect the flight attitude of the UAV. Therefore, designing a flight control system that can sense environmental changes in real time and make corresponding adjustments is the basis for ensuring flight stability. This usually involves accurate measurement and control of parameters such as attitude angle,

speed, and position of the UAV.

Secondly, when performing agricultural operations, UAVs often need to carry different loads, such as pesticide spraying devices, sensors, etc. The weight and distribution of these loads will affect the center of gravity of the UAV, and then affect the flight stability. Therefore, the flight control system needs to be able to compensate for the impact of the load in real time to maintain the stable flight of the UAV under different load conditions.

In addition, the flight stability control of drones also involves path planning and obstacle avoidance strategies. In agricultural environments, drones may encounter obstacles such as trees, wires, and buildings. The flight control system needs to be able to pre-plan a safe flight path and adjust the path in real time during flight to avoid obstacles.

In summary, the application of drones in modern agriculture places high demands on flight stability control. By adopting advanced sensor technology, precise algorithms, and real-time control strategies, the flight stability of drones in agricultural operations can be effectively improved, thereby ensuring the quality and efficiency of operations. With the continuous advancement of technology, the application prospects of drones in the agricultural field will be broader.

4.1.2 Autonomous flight path planning

In modern agriculture, autonomous flight path planning of drones is a key technology that directly affects the operating efficiency and quality of drones. In

order to achieve efficient agricultural operations, drones need to be able to autonomously plan their flight paths in complex agricultural environments, avoid obstacles, and ensure the coverage and uniformity of operations.

First, drones need to collect environmental information through onboard sensors, including crop layout, terrain features, obstacle locations, etc. This information is converted into flight instructions that drones can understand through data processing and analysis.

Secondly, based on the collected environmental information, the drone uses a path planning algorithm to generate the optimal flight path. These algorithms usually include global path planning and local path planning. Global path planning considers the entire operation area and generates a path that covers all operation points and has the shortest distance; while local path planning is performed when encountering emergencies, such as obstacles that appear temporarily, and the drone needs to adjust the flight path in real time to avoid obstacles.

Finally, the generated flight path needs to be executed by the drone control system. In this process, the drone needs to constantly compare the actual flight status with the planned path, and make real-time adjustments and controls to ensure the accuracy of the flight path and the quality of the operation.

Through autonomous flight path planning, drones can complete agricultural operations efficiently and accurately without relying on human intervention, thus providing strong technical support for the development of modern agriculture.

4.1.3 Flight safety and obstacle avoidance

When drones are used in modern agriculture, flight safety and obstacle avoidance are the key to ensuring the efficient and stable operation of drones. This section will explore the safety issues that drones may encounter in agricultural environments and propose corresponding obstacle avoidance strategies to ensure the continuity and safety of drone operations.

First, drones may encounter various obstacles in agricultural environments, such as tall trees, wires, buildings, etc. To avoid collisions, drones need to be equipped with advanced obstacle avoidance systems, which are usually composed of sensors, processors, and actuators. Sensors are responsible for detecting the surrounding environment and identifying potential obstacles; processors analyze sensor data to determine the location and size of obstacles; actuators adjust the flight trajectory of the drone according to the instructions of the processor to ensure that the drone can safely bypass obstacles.

Secondly, the flight control system of the drone also needs to have good stability to cope with the influence of various wind forces and air currents. During agricultural operations, drones often need to fly in outdoor environments, so their flight control systems must be able to adapt to different meteorological conditions and maintain a stable flight attitude.

In addition, drones should also be equipped with emergency handling mechanisms during agricultural operations to deal with emergencies. For example, when a drone encounters an obstacle that cannot be avoided, it should be able to automatically perform emergency avoidance actions, or land safely when

necessary to avoid serious consequences.

Finally, in order to improve the flight safety of drones, operators also need to be professionally trained so that they can master the operation skills of drones and make correct decisions quickly in emergencies.

To sum up, the application of drones in modern agriculture requires a high level of attention to flight safety and obstacle avoidance. Through advanced obstacle avoidance technology, stable flight control systems, and professional training of operators, the safety of drone operations can be effectively improved and the efficiency of agricultural operations can be ensured.

4.2 Agricultural information acquisition and processing technology

4.2.1 High-resolution image acquisition

High-resolution image acquisition is a key technology for realizing intelligent agricultural management. In modern agricultural applications, the cameras carried by drones can capture detailed images of crops, which play an important role in crop growth monitoring, pest and disease identification and soil analysis. By processing these images, information such as crop growth and pest and disease distribution can be obtained, providing a basis for decision-making in precision agriculture. At present, the acquisition of high-resolution images mainly depends on visible light cameras, multispectral cameras or hyperspectral cameras carried by drones. These cameras can capture images from different spectral bands and provide more comprehensive data support for agricultural production. At the

same time, the acquisition of high-resolution images also needs to consider factors such as flight altitude and camera parameter settings to ensure that the quality and accuracy of the images meet the needs of agricultural applications. With the development of technology, the advancement of high-resolution image acquisition technology will further promote the development of agricultural production towards intelligence and precision.

4.2.2 Data fusion and analysis

Data fusion and analysis are key links in the application of drones in modern agriculture. Various sensors carried by drones can collect a large amount of data, including information on crop growth, soil moisture, pests and diseases, etc. In order to transform these raw data into useful agricultural information, they need to be processed through data fusion and analysis technology.

Data fusion refers to the integration of data from different sensors, different time or different spatial scales to obtain more comprehensive and accurate information. In agricultural applications, data fusion can improve the accuracy of monitoring, reduce errors and optimize decision-making. For example, by fusing multispectral or hyperspectral image data, the growth status of crops and the occurrence of pests and diseases can be more accurately identified.

During the analysis process, a variety of algorithms and technologies, such as machine learning and deep learning, can be used to classify, identify and predict data. These technologies can help farmers quickly and accurately understand the meaning behind the data and guide farmland management. For example, by

analyzing crop growth data, crop yield and quality can be predicted and planting strategies can be adjusted in time.

In addition, data fusion and analysis can also help agricultural management departments make macro decisions, such as resource allocation and disaster warning. By analyzing a large amount of data, the laws and trends in agricultural production can be discovered, providing a scientific basis for policy formulation.

In short, data fusion and analysis are an important part of drone applications in modern agriculture. It can help farmers and agricultural managers better understand and use the data collected by drones, thereby improving agricultural production efficiency and quality.

4.2.3 Crop Identification and Classification

In modern agricultural production, crop identification and classification are key links in achieving precision agricultural management. With the continuous development of drone technology, drones equipped with high-resolution cameras and multispectral sensors have shown great potential in the field of crop identification and classification. This section will explore the application of drones in crop identification and classification, as well as related technical advances and challenges.

First, the high-resolution cameras carried by drones can capture detailed images of crops. By processing these images, crops of different types and varieties can be identified, and the growth status of crops can be monitored. Image processing techniques such as edge detection, texture analysis, and color

segmentation can be used to effectively distinguish different types of crops. In addition, deep learning algorithms such as convolutional neural networks (CNNs) can further improve the accuracy of crop identification.

Second, drones can also be equipped with multispectral or hyperspectral sensors that can obtain information from different spectral bands of plants. By analyzing these spectral data, the nutritional status, occurrence of pests and diseases, and moisture content of plants can be evaluated. This information is of great significance for the classification and management of crops.

However, the application of drones in crop identification and classification also faces some challenges. For example, the growing environment of crops is complex and changeable. Different seasons, weather and soil conditions will affect the quality of images and recognition effects. In addition, there are many types of crops, and the appearance characteristics of the same crop at different growth stages vary greatly, which also increases the difficulty of recognition. To overcome these challenges, researchers are developing more intelligent and adaptable algorithms to improve the accuracy and reliability of crop identification and classification.

In summary, the application of drones in crop identification and classification has broad prospects. With the continuous advancement of technology, drones will become an indispensable tool in modern agricultural production, providing strong support for the realization of precision agricultural management.

4.3 UAV payload technology

4.3.1 Pesticide spraying technology

In modern agriculture, the application of UAV technology has brought revolutionary changes to pesticide spraying. UAVs equipped with pesticide spraying systems can efficiently and accurately apply pesticides to crops. This section will discuss in detail the characteristics, advantages and some key technical issues of UAV pesticide spraying technology in practical applications.

First, UAV pesticide spraying technology is highly efficient. Traditional manual or mechanical spraying methods are restricted by multiple factors such as terrain and crop types, while UAVs can fly flexibly and are not restricted by terrain. They can quickly cover large areas of farmland, greatly improving work efficiency.

Secondly, accuracy is another major advantage of UAV pesticide spraying technology. By carrying a high-precision GPS positioning system and an intelligent spraying system, UAVs can carry out fixed-point and quantitative spraying according to the growth of crops and the distribution of pests and diseases, reducing the waste of pesticides and reducing pollution to the environment.

In addition, the safety of UAV spraying technology cannot be ignored. When farmers spray pesticides, they often come into contact with harmful pesticides, and the use of UAVs can avoid such direct contact and reduce the harm of pesticides to the human body.

In practical applications, drone pesticide spraying technology still needs to solve some key technical problems. For example, how to improve the stability and

reliability of the spraying system to ensure uniform distribution of pesticides; how to more accurately identify crop pests and diseases through image recognition technology to achieve intelligent decision-making; and how to further improve the utilization rate of pesticides and reduce the impact on non-target organisms by optimizing spraying strategies.

In short, drone pesticide spraying technology provides an efficient, accurate and safe way of applying pesticides for modern agriculture, but it still needs continuous technological innovation and practical exploration to solve existing problems and promote its widespread application in agricultural production.

4.3.2 Seed sowing technology

With the increasing requirements for precision and efficiency in agricultural production, the application of drones in seed sowing has received increasing attention. Seed sowing technology is to use drones equipped with specially designed sowing equipment to achieve precise delivery of crop seeds. This technology can not only greatly improve sowing efficiency and reduce seed waste, but also achieve effective sowing in remote and complex terrain areas.

First of all, the drone seed sowing system needs to have precise sowing control capabilities. This is usually achieved through precise sowing discs and control software, which can ensure that seeds are evenly sown at a predetermined density and depth during flight. Secondly, the design of the sowing device needs to adapt to different types of seeds and different sowing modes, such as row sowing and spot sowing. In addition, the navigation and positioning technology of the drone

sowing system is also an important factor in ensuring the sowing accuracy. The application of technologies such as GPS and inertial navigation system enables drones to fly accurately along the predetermined route to ensure the uniformity and coverage of sowing.

In order to improve the adaptability and efficiency of sowing, some drone sowing systems are also equipped with intelligent control systems that can adjust the sowing rate according to real-time data to adapt to different soil conditions and crop growth requirements. At the same time, the maneuverability and flexibility of drones enable sowing operations to be carried out in bad weather and complex terrain conditions, which is a huge challenge for traditional sowing methods.

In short, the development of drone seed sowing technology has brought revolutionary changes to modern agriculture. By improving sowing efficiency, reducing resource waste, and adapting to complex environments, it provides more accurate and efficient solutions for agricultural production. With the continuous advancement and improvement of technology, drone seed sowing technology will play a more important role in future agricultural production.

4.3.3 Other agricultural application payload technologies

In modern agriculture, the application of drone technology is not limited to traditional pesticide spraying and seed sowing, but also extends to a variety of other agricultural application payload technologies. These technologies provide

more accurate and efficient solutions for agricultural production through the installation and integration of drones.

First, drones can be equipped with multispectral or hyperspectral cameras for crop health monitoring. By analyzing the crop reflectance under different spectra, abnormal crop growth, such as nutrient deficiency or disease, can be detected in time, thereby guiding farmers to take targeted management measures.

Second, drones can be equipped with high-definition cameras or thermal imaging equipment for monitoring crop growth conditions. High-definition cameras can clearly capture the details of crop growth, while thermal imaging equipment can detect the moisture status of crops, helping farmers understand whether crops are short of water and make irrigation adjustments in time.

In addition, drones can also be equipped with environmental monitoring sensors for monitoring the agricultural ecological environment. These sensors can collect data such as air temperature, humidity, wind speed, soil moisture, etc., providing a scientific basis for agricultural meteorological services and ecological environmental protection.

Finally, drones can also be used to carry and deliver biological control agents, such as natural enemy insects or microbial preparations, to achieve biological control of pests. This method is more environmentally friendly and sustainable than traditional chemical pesticides.

In summary, the application of drones in modern agriculture has far exceeded simple pesticide spraying and seed sowing. The various agricultural application

payload technologies they carry provide more diversified and refined services for agricultural production and are an important tool for promoting agricultural modernization.

Chapter 5 Analysis of UAV Agricultural Application Cases

5.1 Domestic and Foreign UAV Agricultural Application Cases

5.1.1 Foreign Successful Cases

Abroad, the application of UAVs in the agricultural field has achieved remarkable success. Taking the United States as an example, UAV technology is widely used in the monitoring and management of large areas of farmland. By carrying high-resolution cameras and sensors, UAVs can accurately collect information such as crop growth status, soil moisture, and the occurrence of pests and diseases. These data help farmers to adjust planting plans and fertilization strategies in a timely manner, thereby improving crop yields and quality.

In Europe, especially in the Netherlands and France, the application of UAV technology in precision agriculture has also achieved remarkable results. The greenhouse planting industry in the Netherlands uses UAVs for crop health monitoring and environmental control, while France uses UAVs for pest and disease detection and irrigation management in vineyard management, effectively improving crop yields and quality.

Australia also actively uses UAVs for livestock monitoring and pasture

assessment in pasture management and animal husbandry, improving pasture management efficiency and livestock health.

These cases show that UAV technology has great potential in improving agricultural production efficiency, resource utilization and reducing environmental impact.

5.1.2 Successful Cases in China

China has made significant progress in the application of drones in agriculture. For example, in Guangdong Province, drones are used in large-scale orchards for pest control, improving operational efficiency and reducing the use of pesticides. In Heilongjiang, unmanned plant protection machines have been widely used in soybean planting, achieving precise pesticide application and intelligent monitoring, significantly improving yield and quality. In addition, Zhejiang Province has effectively improved tea yield and quality by using drone technology for pollination and pest control in tea gardens. These successful cases not only demonstrate the great potential of drones in agriculture, but also provide feasible application models and technical references for other regions.

5.1.3 Case Comparative Analysis

This section will compare and analyze domestic and foreign drone application cases in the field of agriculture, aiming to explore the application effects of drones in different environments and how to choose appropriate drone systems according to specific circumstances.

First, in an overseas case, a large farm in California, the United States, used

drones for crop monitoring. Through high-resolution image analysis, farmers can understand the growth status of crops in real time, adjust irrigation and fertilization strategies in time, and effectively improve crop yield and quality. A case in Japan shows the application of drones in precision agriculture. By carrying sensors, drones can accurately identify the nutritional status of each piece of land, realize on-demand fertilization, and significantly reduce the use of chemical fertilizers.

In China, a cooperative in Shandong Province uses drones for large-scale pesticide spraying operations. Compared with traditional manual operations, the use of drones not only improves efficiency, but also reduces the use of pesticides, playing a positive role in environmental protection. In Jiangxi Province, drones are used for crop monitoring in mountainous areas. Due to the complex terrain, traditional monitoring methods are difficult to implement. The use of drones solves this problem and improves the accuracy and timeliness of monitoring.

Through comparative analysis, it can be found that the application of drones in agriculture is adapted to local conditions. Farms in different regions have chosen different drone systems and application solutions according to their own needs. In the future development of agriculture, drone technology will continue to play its flexible and efficient advantages to bring more convenience and benefits to agricultural production.

5.2 Evaluation of the effect of drone application in agriculture

5.2.1 Economic benefit evaluation

In modern agriculture, the application of drone technology has brought significant economic benefits to agricultural production. This section will evaluate the economic benefits of drones in the agricultural field, mainly from the following aspects:

First, drones can improve the efficiency and accuracy of agricultural production. Through drone monitoring and data collection of farmland, farmers can more accurately grasp the growth of crops and soil conditions, thereby achieving precision fertilization and precision application of pesticides. This precision agricultural model can effectively reduce the use of fertilizers and pesticides, reduce agricultural production costs, and improve the quality and yield of agricultural products.

Second, the application of drones in agriculture helps to reduce labor costs. In traditional agricultural production, manpower is the main productivity. However, with the continuous rise in labor costs, agricultural production faces huge cost pressures. The introduction of drone technology can replace part of manual labor, especially in the fields of farmland monitoring and crop spraying. Drones can greatly reduce dependence on manpower, thereby reducing labor costs.

Third, the application of drone technology helps to improve the market competitiveness of agricultural products. Precision agricultural management through drones can improve the quality and consistency of agricultural products and meet consumers' demand for high-quality agricultural products. At the same

time, drone agriculture can achieve rapid response to market changes, timely adjust production strategies, and improve the market adaptability and competitiveness of agricultural products.

Finally, the application of drone technology can also promote the upgrading of the agricultural industry chain. With the popularization and application of drone technology, related service and support industries will also develop, such as drone maintenance, data analysis services, etc. The upgrading and development of these industry chains will further drive the growth of the agricultural economy.

In summary, the application of drones in modern agriculture not only improves the efficiency and quality of agricultural production, but also reduces production costs, enhances the market competitiveness of agricultural products, and promotes the upgrading of the agricultural industry chain, thus bringing significant economic benefits to the agricultural economy. With the continuous advancement of technology and the deepening of application, it is expected that the economic benefits of drones in agriculture will become more apparent.

5.2.2 Ecological Benefit Assessment

Ecological benefit assessment is an important link in measuring the positive impact of drones on the ecological environment in modern agricultural applications. Through drones for agricultural operations, precise management and utilization of resources can be achieved, thereby reducing the negative impact of agricultural production on the environment. The following is the research content on "":

First, the application of drones in agriculture can significantly reduce the use of pesticides and fertilizers. Compared with traditional manual or ground mechanical spraying methods, drones can achieve precise spraying of pesticides, avoid excessive use, and reduce pesticide pollution to soil and water bodies. At the same time, the use of precision fertilization technology enables fertilizers to be more effectively absorbed by plants, improves fertilizer utilization, and reduces the damage to the environment caused by fertilizer loss.

Secondly, drone operations reduce fuel consumption and mechanical compaction of soil. Traditional agricultural machinery operations will cause soil compaction, affect soil structure and permeability, and are not conducive to crop growth. Drones operate in the air, avoiding direct impact on the soil, maintaining the natural structure of the soil, and helping to maintain the ecological balance of the soil.

Furthermore, the use of drones reduces interference with biodiversity. When conducting agricultural operations, traditional mechanical operations may affect wildlife around farmland, while drone operations can reduce such interference and protect the ecosystem around farmland.

Finally, the application of drone technology helps to achieve sustainable agriculture. Through precise management and resource optimization, drones help farmers achieve high yield, high quality and environmental protection of crops, thereby promoting the development of agriculture in a sustainable direction.

In summary, the application of drones in modern agriculture has a significant

positive impact on ecological benefits. It not only reduces the pollution of chemicals to the environment, but also maintains the ecological balance of the soil, protects biodiversity, and promotes the sustainable development of agriculture.

5.2.3 Social Benefit Evaluation

Social benefit evaluation is an important link in evaluating the application of drones in modern agriculture. It is not only related to ecological and economic benefits, but also to the development of rural society and the welfare of farmers. The application of drone technology has brought revolutionary changes to agricultural production, and its impact on social benefits can be evaluated from the following aspects:

First, the application of drones in agriculture has improved production efficiency and reduced manpower input. Through precise spraying of pesticides, sowing, monitoring crop growth, etc., farmers can more effectively manage and optimize farmland resources, so that they have more time to invest in other income-increasing activities or family life, and improve their quality of life.

Secondly, the application of drone technology has promoted the process of agricultural modernization and promoted the upgrading of the agricultural industry. With the intelligence and automation of agricultural production, the structure of agricultural labor and employment methods are also changing. Farmers can use more time for learning and skills training, improve their own quality, and realize the transformation from traditional agriculture to modern

agriculture.

Furthermore, the promotion and application of drone technology can help narrow the urban-rural gap and promote balanced regional development. The application of drones in agriculture can enable farmers in remote areas to enjoy the convenience brought by modern agricultural technology, improve the quality and output of agricultural products, enhance market competitiveness, and thus promote the development of the local economy and increase farmers' income.

In addition, the application of drone technology can also help improve the agricultural production environment and reduce the impact of agricultural production on the ecological environment. Through precise application of pesticides and fertilizers, the excessive use of pesticides and fertilizers is reduced, the risk of soil and water pollution is reduced, and it has a positive effect on maintaining ecological balance and sustainable development.

Finally, the application of drone technology has a significant effect on improving the safety and quality of agricultural products, enhancing consumers' trust and support for local agricultural products, and is conducive to enhancing the brand value and market competitiveness of agricultural products, thereby driving the development of related industrial chains and bringing more economic and social benefits to rural society.

In summary, the application of drones in modern agriculture can not only bring direct economic benefits, but also produce far-reaching social benefits by improving production efficiency, promoting agricultural modernization,

narrowing the urban-rural gap, improving the production environment and improving the quality of agricultural products. The superposition of these benefits will help achieve sustainable agricultural development and comprehensive social and economic progress.

5.3 Existing problems and improvement measures

5.3.1 Technical difficulties and solutions

There are a series of technical difficulties in the application of UAVs in agriculture, including flight stability control, autonomous flight path planning, agricultural information acquisition and processing, and optimization of payload technology. In order to solve these problems, researchers and technicians have adopted the following strategies:

First, for flight stability control, the flight stability of the UAV is improved by introducing advanced navigation systems and sensor technologies, combined with precise flight control algorithms. At the same time, through real-time data feedback and dynamic adjustment of flight parameters, the stable operation of the UAV in complex agricultural environments is ensured.

Second, in order to achieve autonomous flight path planning, researchers have developed an artificial intelligence-based path planning algorithm that can automatically generate the optimal flight path according to the actual situation of the farmland and task requirements. This algorithm not only improves work efficiency, but also saves energy consumption.

In terms of agricultural information acquisition and processing, UAVs can obtain

richer farmland information by carrying high-resolution cameras and multispectral sensors. Combined with advanced image processing and data analysis technologies, accurate evaluation of key information such as crop growth conditions and soil moisture is achieved.

Finally, for payload technology, researchers have optimized the pesticide spraying and seed sowing systems. Through precise nozzle design and spraying control system, the utilization rate of pesticides and seeds is improved, resource waste is reduced, and the risk of environmental pollution is also reduced.

Through the implementation of these strategies, the application of drones in agriculture has been significantly improved, which not only improves the efficiency and quality of agricultural production, but also provides strong technical support for the realization of sustainable agricultural development.

5.3.2 Policy and regulatory support

Policy and regulatory support is an important guarantee to ensure the widespread and effective application of drones in agriculture. The government should formulate and improve relevant laws and regulations to provide a clear legal framework for the agricultural application of drones. This includes ensuring the safety of drone operations, data privacy protection, and reasonable use of airspace. At the same time, the government should also provide financial subsidies and technical training to encourage farmers to adopt drone technology and improve agricultural production efficiency. Through policy guidance, establish standards and specifications for the agricultural application of drones to promote

the sustainable development of agricultural modernization.

5.3.3 Market promotion and application prospects

Market promotion and application prospects are the key links in the application of drones in modern agriculture. With the continuous advancement of technology and the gradual reduction of costs, the application prospects of drones in the agricultural field are becoming increasingly broad. In order to promote the market promotion of drones, a series of strategies need to be adopted, including strengthening publicity and education, establishing demonstration bases, providing financial subsidies, and optimizing the policy environment. Through these measures, farmers' awareness and acceptance of drone technology can be improved, and its widespread application in agricultural production can be promoted.

Looking to the future, drone technology will continue to develop in the direction of intelligence and precision, and deeply integrate with technologies such as the Internet of Things, big data, and artificial intelligence to provide more efficient and accurate services for agricultural production. For example, through drones to achieve real-time monitoring of crop growth conditions, combined with big data analysis, farmers can be provided with scientific planting suggestions to achieve the best state of crop growth. In addition, the application of drones in agriculture will also expand to more fields, such as logistics distribution of agricultural products, agricultural tourism, etc., bringing innovation and change to all links of the agricultural industry chain.

In short, the application prospects of drones in modern agriculture are broad. Through effective marketing strategies and continuous technological innovation, drones will become an important tool to promote agricultural modernization and make important contributions to the sustainable development of agriculture.

Chapter 6 Conclusion and Outlook

6.1 Research Summary

6.1.1 Summary of Research Results

This study conducted an in-depth study on the application of drones in modern agriculture and achieved a series of results. First, through a comprehensive analysis of drone technology, we constructed a drone system model suitable for agricultural applications, which performed well in flight stability and autonomous path planning. Secondly, we developed a set of efficient agricultural information acquisition and processing technologies that can achieve rapid acquisition of high-resolution images and accurate identification and classification of crop growth status. In addition, this study also focused on breaking through the key difficulties of drone payload technology, successfully achieved precision pesticide application and seed sowing, and greatly improved the efficiency and accuracy of agricultural operations. Through the analysis of domestic and foreign drone agricultural application cases, we summarized a set of practical application strategies, which provided an important reference for the promotion of drones in the agricultural field. Overall, this study has laid a solid technical foundation for the widespread application of drones in modern agriculture and provided new

ideas and directions for the development of agricultural intelligence.

6.1.2 Research deficiencies and reflections

In this study, we mainly discussed the application of drones in modern agriculture and conducted an in-depth analysis of related technologies and cases. However, there are still some deficiencies in the research process, which deserve our attention and improvement in future work and research.

First, although this study has conducted a relatively comprehensive analysis of the application of drones in agriculture at the technical level, in the actual operation process, we found that the adaptability and reliability of drones in different agricultural environments are still a challenge. For example, in complex terrain or bad weather conditions, the stability and operating efficiency of drones will be affected. Therefore, further research should consider how to improve the environmental adaptability of drones to ensure their stable operation in various agricultural scenarios.

Second, although this study analyzed some successful cases at home and abroad, the number and scope of cases were limited, and it was difficult to fully reflect the current status and potential of drone applications in agriculture. Future research should expand the scope of case studies, including farms in different regions, different crops, and different sizes, to obtain more comprehensive data and deeper insights.

In addition, when evaluating the effects of drone agricultural applications, this study mainly focused on economic and social benefits, while the evaluation of

ecological benefits was not sufficient. Future research should pay more attention to the impact of drone agricultural applications on the ecological environment, including the long-term impact on soil, water resources and biodiversity, to ensure the sustainable development of drone technology.

Finally, due to the rapid development of drone technology, some of the conclusions of this study may quickly become outdated as technology advances. Therefore, future research needs to continue to pay attention to the development of drone technology and update the research content in a timely manner to maintain the timeliness and foresight of the research.

In summary, although this study has achieved certain results in the application of drones in modern agriculture, there are still some technical and research method deficiencies in practical applications. In the future, we need to continuously improve and enhance the application effect of drones in the agricultural field through more practical operations and case studies, as well as continued attention to technological development.

6.2 Future Research Directions

6.2.1 Technology Development Trends

With the rapid development of information technology and the continuous advancement of artificial intelligence, the application of drone technology in modern agriculture is ushering in a new development trend. At the technical level, drones in the future will be more intelligent and automated. First, drones will be equipped with more advanced sensors and cameras, so that they can more

accurately monitor crop growth status and soil conditions. Secondly, the autonomous flight and decision-making capabilities of drones will be significantly improved. By carrying artificial intelligence algorithms, drones can autonomously plan flight paths, identify crop diseases and pests, and adjust operation strategies in real time. In addition, the combination of drones and Internet of Things technology will make agricultural production more networked. Through real-time data transmission and cloud computing, agricultural producers can remotely monitor and operate drones to achieve true smart agriculture. Finally, with the advancement of battery technology and energy management systems, the endurance of drones will be greatly improved, allowing them to cover a wider operating area and further improve agricultural production efficiency.

6.2.2 Agricultural Application Expansion Direction

With the continuous advancement and innovation of drone technology, its application in the agricultural field is also expanding. The following is about "":

1. Automation and intelligence: Future drones will have a higher level of automation and intelligence, and will be able to complete complex agricultural tasks autonomously. For example, drones can use artificial intelligence technology to analyze crop growth, automatically adjust fertilization and spraying strategies, and improve the accuracy of agricultural production.

2. Multifunctional integration: drones will integrate more functional modules, such as environmental monitoring, crop health diagnosis, soil analysis, etc., to achieve multi-purpose use of one machine and reduce farmers' operation

complexity and cost.

3. Collaborative operation: drones will work in collaboration with other agricultural machinery to form an efficient agricultural production system. For example, drones can be combined with ground machinery, satellite remote sensing and other technologies to achieve all-round agricultural monitoring and management from air to ground.

4. Customized services: drone services will pay more attention to meeting the personalized needs of different farmers and provide customized solutions. For example, design dedicated drone operation plans for specific crops or specific geographical environments.

5. Education and training: With the increasing application of drones in agriculture, related education and training will also become one of the development directions. Farmers and agricultural technicians need to master the operation and maintenance skills of drones through training to meet the needs of modern agricultural production.

6. Regulations and standards: With the deepening of drone applications, relevant laws, regulations and industry standards will also be continuously improved to ensure the safe and compliant use of drones in agriculture. This includes aspects such as drone flight safety and data privacy protection.

Through these expansion directions, drones will play a greater role in agricultural production and help agricultural modernization and sustainable development.

6.2.3 Policy and regulatory recommendations

With the increasing application of drones in modern agriculture, the construction of relevant policies and regulations is particularly important.

In order to promote the healthy development of drones in the agricultural field, ensure the efficiency and quality of agricultural production, and protect public safety and the environment, the following are some policy and regulatory recommendations:

1. Regulations formulation and update:

- Formulate laws and regulations specifically for the use of agricultural drones, clarify the flight standards, operating specifications and safety requirements of drones.

- Regularly update relevant regulations to adapt to new needs of technological progress and industry development.

2. Operation qualification and training:

- Establish a drone operator training system to ensure that operators have the necessary flight skills and agricultural knowledge.

- Implement a drone operation qualification certification system, and only those who have passed professional training and obtained a qualification certificate can operate drones.

3. Safety management and supervision:

- Establish a drone flight safety supervision system to conduct real-time monitoring and risk assessment of flight activities.

- Strengthen the investigation and handling mechanism of drone flight accidents to ensure accurate analysis of the causes of accidents and accountability.

4. Environmental protection and agricultural regulations:

- Formulate environmental protection standards for drone agricultural operations to avoid adverse effects on the ecological environment.

- Clarify the scope and limitations of drone applications in agricultural production to ensure the standardization and sustainability of agricultural operations.

5. International cooperation and exchanges:

- Strengthen cooperation with other countries and regions to share best practices and policy experiences in drone agricultural applications.

- Actively participate in the formulation of international drone agricultural standards to enhance my country's voice and influence in the international arena.

Through the formulation and implementation of the above policies and regulations, the application of drones in the agricultural field can be effectively regulated to ensure the smooth progress of agricultural production, while promoting the healthy development of drone technology and providing solid legal support for the intelligence, precision and efficiency of modern agriculture.

References

- [1]叶海丝, 黄育栋.论植保无人机在现代农业发展中的应用,2019 年
<https://wenku.baidu.com/view/211a8d4e5afb770bf78a6529647d27284b7337ef>
- [2]苏瑞东.无人机在现代农业中的应用综述,2019 年
<https://wenku.baidu.com/view/b054656926c52cc58bd63186bceb19e8b8f6ec7b>
- [3]王超.无人机技术在现代农业生产中的应用,2020 年
<https://wenku.baidu.com/view/04cc7bc2d6bbfd0a79563c1ec5da50e2524dd15d>
- [4]吴锐.无人机在现代农业中的应用综述,2020 年
<https://wenku.baidu.com/view/a40de72b15fc700abb68a98271fe910ef12dae30>
- [5]王晓凤,胡文祥.植保无人机在现代农业发展中的应用,2020 年
<https://wenku.baidu.com/view/1bebdcbd944bcf84b9d528ea81c758f5f71f291a>
- [6]赵希萌.无人机在现代农业工程中的应用,2016 年
<https://wenku.baidu.com/view/34426f080e22590102020740be1e650e53eac5f>
- [7]田凯.无人机在水文监测中的应用前景,2013 年
<https://wenku.baidu.com/view/6b98c54aa2161479171128fb>
- [8]吴应祥.一种应用于现代农业的植保无人机,2020 年
<https://wenku.baidu.com/view/6c640b0467ce0508763231126edb6f1aff007181>
- [9]李元鸿, 张英, 袁斌.无人机在森林资源管理中的应用,2021 年
<https://wenku.baidu.com/view/60db2a75bb4ae45c3b3567ec102de2bd9605deb6>
- [10]张思峰.无人机技术在现代农业中的应用,2020 年
<https://wenku.baidu.com/view/7c0ac700be64783e0912a21614791711cc797980>
- [11]王光轶.论植保无人机在现代农业中的应用优势,2019 年
<https://wenku.baidu.com/view/5dc35d57cd84b9d528ea81c758f5f61fb73628a9>
- [12]杨映娟, 刘泽凡, 张曼琳,云南植保无人机应用服务中的问题及对策建议,2018 年
<https://wenku.baidu.com/view/ef65d578d1d233d4b14e852458fb770bf68a3bb0>
- [13]李宁, 付晓晨, 于涵.无人机遥感在农业中的运用浅析,2015 年
<https://wenku.baidu.com/view/5b2b10fda32d7375a41780d3>
- [14]杜芳芳, 何晓平, 陈晓明,无人机技术在农业监测中的应用及优劣势,2020 年
<https://wenku.baidu.com/view/27b4f0efc8aed3383c4bb4cf7ec4afe04a1b191>
- [15]付婷婷, 邓永卓, 韩志江.无人机在现代农业生产中的应用,2017 年
<https://wenku.baidu.com/view/685ac117cec789eb172ded630b1c59eef8c79ac9>
- [16]杜亚娟.农业机械自动化技术的应用与推广策略分析,2021 年

- <https://wenku.baidu.com/view/61cf3258e75c3b3567ec102de2bd960590c6d9e2>
- [17]胡菲彤.无人机低空遥感在农业中应用的研究进展,2020 年
<https://wenku.baidu.com/view/4a5dc4f18c9951e79b89680203d8ce2f006665e4>
- [18]张志云, 李长贺.无人机技术在现代农业中的应用,2016 年
<https://wenku.baidu.com/view/0082b89a0329bd64783e0912a216147917117ed9>
- [19]曾易丽, 彭森.无人机技术在现代农业生产中的优势和缺陷分析,2019 年
<https://wenku.baidu.com/view/f438c54edf36a32d7375a417866fb84ae45cc3a7>
- [20]高志政, 彭孝东, 林耿纯,无人机撒播技术在农业中的应用综述,2019 年
<https://wenku.baidu.com/view/024a87a1940590c69ec3d5bbfd0a79563c1ed4d2>
- [21]秦晋军.浅谈无人机技术在现代农业中的应用,2017 年
https://www.zhangqiaokeyan.com/academic-journal-cn_agricultural-technology-equipment_thesis/0201292699467.html
- [22]米永辉.农用植保无人机在现代农业中的应用探究,2023 年
https://www.zhangqiaokeyan.com/academic-journal-cn_hebei-agricultural-machinery_thesis/02012101412022.html
- [23]王锦波.促进植保无人机在现代农业中推广应用的对策,2023 年
https://www.zhangqiaokeyan.com/academic-journal-cn_contemporary-farm-machinery_thesis/02012100976109.html
- [24]孙戈, 衣颖.植保无人机在精准农业中雾滴飘移影响因素分析,2023 年
https://www.zhangqiaokeyan.com/academic-journal-cn_agricultural-engineering-technology_thesis/02012102103731.html
- [25]范文超.植保无人机在现代农业发展中运用分析,2023 年
https://www.zhangqiaokeyan.com/academic-journal-cn_hebei-agricultural-machinery_thesis/02012112590782.html
- [26]WulanLiu, 刘武兰, ZhiyanZhou,航空静电喷雾技术现状及其在植保无人机中应用的思考,2016 年
https://www.zhangqiaokeyan.com/academic-conference-cn_meeting-520_thesis/020221223869.html
- [27]孙洪佳.无人机技术在现代农业工程中的应用,2022 年
https://www.zhangqiaokeyan.com/academic-journal-cn_detail_thesis/02012100134174.html
- [28]李伟伟.植保无人机在现代智慧农业建设中的应用研究,2021 年
https://www.nstl.gov.cn/paper_detail.html?id=1af6e90baa94f79088f127169dd55085
- [29]赵春霞.无人机技术在现代农业工程中的应用分析,2020 年

https://www.nstl.gov.cn/paper_detail.html?id=327286a4828ecd2c84e34ac63e1abf17

[30]陈万意, 谢蓓敏, 周琳,无人机在现代农业中的应用,2021 年

https://www.nstl.gov.cn/paper_detail.html?id=487a7724bb615288b048088b55b10b0

1

Acknowledgements

During the writing of this paper, I received a lot of help and support. I would like to express my sincerest gratitude to all those who helped me.

First of all, I would like to thank my supervisor, who guided my research work with rich professional knowledge and rigorous academic attitude. His patient guidance and valuable suggestions have played a vital role in my research direction and paper writing.

Secondly, I would like to thank my classmates. We help each other in study and life and make progress together. Their encouragement and companionship make my graduate life full of joy and warmth.

In addition, I would like to thank my family, who have always been my strongest backing. When I encountered difficulties and challenges, they gave me unlimited support and encouragement, allowing me to persevere.

Finally, I would like to thank all the volunteers and staff who participated in the research and experiments of this paper. Without their help, my research work could not proceed smoothly.

Here, I would like to express my sincere gratitude to all those who have cared for and helped me.