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Research on a Complete Set of Intelligent Agricultural Protection Equipment Based on AIoT and Knowledge Graph Technology for Remote Spectral Flight Control

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Abstract: In response to the problems existing in the traditional extensive agricultural protection mode, such as low monitoring coverage, blind pesticide usage, low herbicide efficiency, and poor adaptability to low-growing crops, combined with the demand for fragmented operations in small-scale farmland in China, this paper has developed a set of intelligent agricultural protection equipment for crops based on AIoT and knowledge graph technology. This equipment integrates high-altitude inspection by drones and ground operation by agricultural protection carts, innovatively applying high-spectrum imaging technology to solve the problem of monitoring low-growing crop canopies, adopting a combined structure of physical cutting and chemical inhibition to optimize the control effect of weeds, and completing the parameter selection of power motors and active shaft servo motors through theoretical calculation and the construction of intelligent algorithms, to achieve a closed-loop operation system of "monitoring - analysis - decision - execution". Through multiple sets of repeated field tests, the accuracy rate of disease and pest detection and weed detection of the equipment reached 97.5%, the chemical pesticide saving rate was 87%, the weed removal rate was 88.3%, and the operation efficiency was 62.5% higher than that of manual operations. All performance indicators met the research goals. The research results show that this equipment is suitable for operations in various terrains, has controllable costs, and can provide low-cost and practical intelligent agricultural protection solutions for small-scale farmland, effectively filling the gap in precise agricultural protection technology for low-growing crops, improving the integration application system of AIoT and knowledge graph technology in the field of smart agriculture, and having important theoretical value and practical significance for promoting agricultural cost reduction and efficiency improvement and green sustainable development.

Keywords: AIoT; Hyperspectral Imaging; Spectral-Enabled Flight Control; Intelligent Weeding Knowledge Graph.

1. Introduction

As the process of agricultural modernization in our country continues to advance, agricultural production is gradually transforming towards precision, green, and intelligence. However, there are still many bottlenecks in the management of grassroots farmland. The accelerated urbanization process has led to a continuous reduction in the area of cultivated land, and production materials such as pesticides and water resources have become increasingly scarce. The traditional extensive pest control model has problems such as low monitoring coverage, blind pesticide use, low herbicide efficiency, and poor adaptability to short plants. This not only causes high production costs but also leads to environmental problems such as soil pollution and water eutrophication, seriously restricting the sustainable development of agriculture.

Data shows that the coverage rate of field monitoring equipment in China is only 27.8%, and over 70% of farmland has not achieved effective monitoring. Crop disease and pest warnings are not timely, and the annual yield loss due to diseases and pests is over 15%. In traditional pest control operations, the phenomenon of random mixing of pesticides and full coverage spraying is widespread, and the pesticide utilization rate is less than 30%, causing a large amount of resource waste. To address the practical pain points of large-scale planting of low-growing crops such as Chinese cabbage, which have high planting density, severe canopy shading, and poor adaptability to existing pest control technologies, a set of intelligent equipment integrating precise monitoring, efficient weeding, and reduced pesticide spraying has been developed. This is an urgent need to promote agricultural green development and improve production efficiency.

In recent years, the application of cutting-edge technologies such as AIoT, hyperspectral imaging, and knowledge graphs in the agricultural field has gradually deepened, providing technical support for the development of intelligent pest control equipment. Hyperspectral imaging technology, with its precise spectral feature recognition ability, shows unique advantages in crop health monitoring, but it is currently mainly applied to tall crops and the adaptability of this technology in low-growing crop monitoring is still in a blank state; AIoT technology realizes equipment collaboration and real-time data transmission, but has not yet been deeply integrated with knowledge graphs and mechanical operations, making it difficult to form a closed-loop system of "monitoring - analysis - decision-making - execution".

Based on this, this paper develops a set of spectrally-equipped integrated smart agricultural pest control equipment based on AIoT and knowledge graph technology, integrating unmanned aerial vehicle high-altitude inspection and ground pest control vehicle operations, innovatively applying hyperspectral imaging technology to solve the problem of low-growing crop monitoring, designing a collaborative weeding structure to optimize the control effect of weeds, and verifying the equipment performance through theoretical calculations and field tests, providing a low-cost, practical smart pest control solution for small-scale farmland, and helping agriculture reduce costs, increase efficiency, and achieve green and sustainable development. The research results of this paper not only can fill the gap in precise pest control technology for low-growing crops, but also can improve the integration application system of AIoT and knowledge graph technologies in smart agriculture, and have important theoretical value and practical significance.

2. Literature Review

2.1. Research Status of Intelligent Agricultural Protection Equipment.

Intelligent agricultural protection equipment is the core carrier for achieving precision agriculture. In recent years, scholars at home and abroad have conducted extensive research on the automation and intelligence of agricultural protection machinery. Developed countries with large-scale agriculture have taken the lead in upgrading agricultural protection equipment with intelligence. Countries such as the United States and the Netherlands have deeply integrated satellite remote sensing, the Internet of Things, and AI algorithms with agricultural protection machinery, developing large-scale agricultural protection equipment with autonomous navigation and variable application capabilities. High-spectrum imaging technology has been successfully applied in the health monitoring of tall crops such as wheat and corn, enabling early warning and precise control of pests and diseases [1]. The self-driving agricultural protection machine developed by John Deere of the United States integrates multi-spectral monitoring and variable application systems, which can dynamically adjust the application dosage according to the growth of crops, significantly improving the efficiency of agricultural protection [1]; The small-scale agricultural protection robot developed by the Wageningen University team in the Netherlands uses machine vision to identify crops and weeds, achieving precise weeding, but this equipment is costly and difficult to adapt to fragmented farmland in China [2]. However, such equipment is costly, relies on large-scale farm operation models, is difficult to adapt to the current situation of small-scale and fragmented farmland in China, and fails to effectively solve the problem of canopy shading in low-growing crops [2].

The research on intelligent agricultural protection equipment in China started relatively late but has developed rapidly. Currently, research mainly focuses on the development and improvement of single-function equipment. Luo Xiwen et al. [3] clearly pointed out in "Improving the Level of Agricultural Mechanization and Promoting Agricultural Sustainable Development" that precise agricultural protection is an important direction for the development of agricultural mechanization, emphasizing the need to break through the traditional bottlenecks of agricultural protection through technological innovation, and pointing out the direction for the research on intelligent agricultural protection equipment in China; Yin Jinsong et al. [4] designed a small-scale fully automatic weeding machine based on a tracked chassis, using mechanical cutting to remove weeds, promoting the miniaturization and automation of weeding machinery, but this equipment lacks monitoring functions and is difficult to achieve precise weeding; Some scholars have applied drone technology to agricultural protection spraying, improving the efficiency of operations, but there are problems such as insufficient monitoring accuracy and poor coordination with ground operations [5]. Ma Haokun et al. [5] in the research on desert automatic supervision robots proposed a multi-device collaborative monitoring idea, providing a reference for the design of land-air collaborative agricultural protection equipment. Overall, domestic research still has obvious shortcomings: most equipment has a single function and has not achieved integrated monitoring, weeding, and spraying; advanced technologies such as high-spectrum imaging have not been applied in low-growing crops; there is a lack of low-cost, practical solutions that can be implemented, and it is difficult to meet the actual needs of grassroots farmers [6]. Shou Derong et al. [6] in the research on agricultural mechanization and rural industrial revitalization pointed out the problem of "high cost and single function" of grassroots agricultural protection equipment, further confirming the necessity of the research in this paper.

2.2. The Application of AIoT and Knowledge Graphs in Smart Agriculture Protection.

AIoT technology, as a fusion product of the Internet of Things and artificial intelligence, achieves real-time collection, transmission and analysis of field data through the collaborative action of sensors, communication modules and intelligent algorithms, providing data support for precise agricultural protection. Currently, AIoT technology has been applied in fields such as crop growth environment monitoring and pest and disease identification, by integrating multiple sources of data to achieve precise location and risk assessment of pests and diseases. However, there is still room for improvement in data fusion accuracy and equipment collaboration efficiency [7]. Ran Hao et al. [7] in the development of a new type of agricultural weed control machinery, integrated a simple IoT module to achieve operation data collection, but did not integrate it with an intelligent decision-making system, making it difficult to form a closed-loop operation; Knowledge graph technology can integrate knowledge from multiple fields such as crop growth patterns, pest and disease control norms, and pesticide usage standards, providing knowledge support for intelligent decision-making. Currently, the application of knowledge graph technology in smart agriculture protection mainly focuses on pest and disease diagnosis, and has not yet deeply integrated with mechanical operations, failing to achieve synchronous linkage of decision-making and execution [8]. Bai Xuefeng et al. [8] in the research on the current situation of agricultural mechanization in China, proposed the need to promote the deep integration of the Internet of Things and agricultural protection machinery, providing a theoretical basis for the integration application of AIoT and knowledge graph in this paper.

2.3. The application of hyperspectral imaging technology in crop monitoring.

High-spectrum imaging technology can capture the spectral characteristic differences of crops under different growth conditions, effectively distinguishing healthy plants, diseased plants, and weeds. It has the advantages of high monitoring accuracy, fast speed, and non-contact nature, and has become an important technical means for crop health monitoring. Foreign scholars have used high-spectrum imaging technology to achieve early identification of crop diseases and pests, with detection accuracy reaching over 95% [9]. For instance, the team from the Agricultural Research Center of the United States Department of Agriculture extracted the chlorophyll content of crop leaves using high-spectrum data, achieving early warning of diseases and pests and a detection accuracy of 96.3% [9]; Chinese scholars have conducted research on the feature extraction and algorithm optimization of high-spectrum data, improving the recognition accuracy in complex environments. However, related studies mainly focused on tall crops and were relatively scarce for monitoring of low-growing crops such as Chinese cabbage, failing to effectively solve the problems of identification errors caused by canopy shading and weed contamination [10]. Wu Qizhao [10] pointed out in his research on the development trend of agricultural mechanization in China that there is a gap in the application of high-spectrum technology in the monitoring of low-growing crops, providing an entry point for the innovation of this paper.

2.4. Review of the Current Research Situation.

Based on the current research status at home and abroad, it can be seen that the research on intelligent agricultural protection equipment, AIoT, hyperspectral imaging, etc. has made certain progress. However, there are still three core issues: First, the existing agricultural protection equipment is difficult to adapt to the planting characteristics of low-growing crops, and the canopy obstruction leads to insufficient monitoring accuracy and poor weeding and spraying effects. Second, AIoT, knowledge graphs, hyperspectral imaging, etc. have not been deeply integrated, lacking a closed-loop system of "monitoring - analysis - decision-making - execution". Third, the equipment costs are high, making it difficult to be widely promoted among grassroots farmers. This paper addresses these issues by developing a complete set of intelligent agricultural protection equipment with optical spectrum control, achieving technological integration and structural innovation, and filling the gap in low-growing crop precision agricultural protection technology. It has clear research goals and innovation points.

3. The overall design and core technology of the equipment

3.1. Equipment R&D Objectives and Design Principles

3.1.1. R&D Objectives

In response to the pain points of the traditional pest control model and the shortcomings of existing technologies, the equipment developed in this paper, the integrated smart agricultural pest control equipment with optical spectrum sensing and flight control, aims to achieve "land-air collaboration, precise coordination, reduced pesticide usage, and low-cost implementation". Specific objectives include: First, achieving precise monitoring of diseases, pests, and weeds in low-growing crops, with an accuracy rate of no less than 97%; second, achieving precise spraying and coordinated weed control, reducing chemical pesticide usage by no less than 85%; third, adapting to various terrains for operation, capable of smoothly passing through muddy, sloping, and furrowed complex terrains; fourth, controlling the equipment cost to provide affordable solutions for small-scale farmers; fifth, achieving integrated operations of monitoring, weed control, and spraying, enhancing field management efficiency.

3.1.2. Design Principles

Equipment design follows four principles: practicality, economy, reliability, and innovation: The practicality principle is to meet the actual needs of grassroots farmers, with simple operation, convenient maintenance, and adaptation to small-scale farmland operations; the economy principle is to optimize hardware selection, simplify structural design, control manufacturing costs, and lower the usage threshold; the reliability principle is to select core components that are resistant to wear and interference to ensure stable operation of the equipment in complex field environments; the innovation principle is to integrate cutting-edge technologies such as AIoT, knowledge graphs, and hyperspectral imaging, innovate structural design, and solve the problems of low-growing crop pest control.

3.2. Overall Structure Design of the Equipment

The land-air integrated smart agricultural pest control equipment based on hyperspectral remote sensing technology consists of a ground pest control vehicle and a drone. It adopts a modular design, facilitating installation, debugging, and maintenance. The overall structure includes a track chassis, radar device, drone start-stop device, weed control device, adjustable pressure spraying device, hyperspectral imaging module, AIoT communication module, etc. as core components. Each module works collaboratively to achieve integrated pest control operations.

The track chassis adopts anti-slip, anti-clogging, and shock-absorbing design, suitable for soft soil, uneven ridges, and other agricultural environments, responsible for the movement of ground operations; the radar device conducts designated range search and obstacle detection, combined with ultrasonic obstacle avoidance system, ensuring the safe movement of the equipment; the drone start-stop device is responsible for the take-off and landing control of the drone, enabling high-altitude inspection and data collection; the weed control device adopts elastic plastic double blades and chemical inhibitors in a collaborative structure to complete precise weed control; the adjustable pressure spraying device realizes high-pressure atomization spraying of pesticides, balancing the operation range and spraying accuracy; the hyperspectral imaging module is mounted on the drone, responsible for capturing crop spectral information and image data; the AIoT communication module realizes data transmission and cloud linkage among various devices, building a closed-loop operation system. The overall rendering diagram of the equipment is shown in Figure 1.

Figure 1. Renderings of the complete agricultural machinery with combined land and air remote sensing technology based on hyperspectral remote sensing technology

3.3. Core Technology Application

3.3.1. Hyperspectral Imaging Monitoring Technology

This research innovatively applies hyperspectral imaging technology to the monitoring of low-growing crops, addressing the problem of canopy obstruction that traditional monitoring techniques struggle to overcome. The unmanned aerial vehicle is equipped with hyperspectral imaging equipment, hovering at high altitudes and conducting extensive cruising. It efficiently collects spectral information and image data of the crops, and promptly feeds them back to the internet platform, enabling visual monitoring of the crop's health status. Hyperspectral imaging technology can capture the spectral characteristic differences of crops under different growth conditions. By extracting key parameters such as leaf reflectance and vegetation index, it effectively distinguishes healthy plants, diseased plants, and weeds, providing data support for precise control and reference [9][10] for hyperspectral data processing methods. To improve the monitoring accuracy in complex environments, the hyperspectral data is preprocessed through noise reduction, filtering, and feature extraction. These operations eliminate the interference caused by light, dust, and field debris, optimize the spectral feature recognition algorithm, and enhance the ability to extract detailed features. Through the initially established smart agriculture internet system, the unmanned aerial vehicle and ground carts are coordinated for surveying, completing the collection, transmission, and management of agricultural health data. The visual map of crop supervision is shown in Figure 2, and the start-stop device of the unmanned aerial vehicle and the agricultural cart are presented in Figure 3.

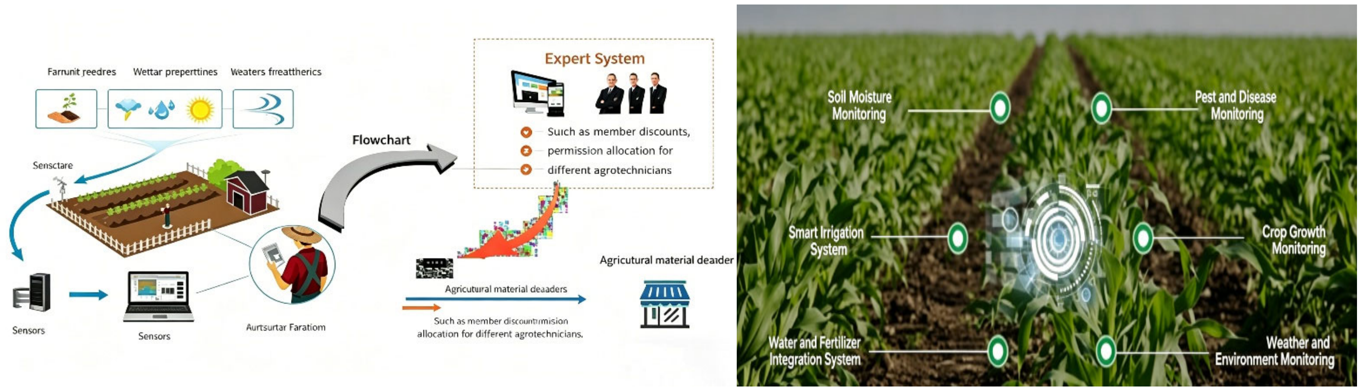

Figure 2. Crop Monitoring Visualization Chart

Figure 3. Unmanned aircraft start-stop device and agricultural vehicle display

3.3.2. AIoT Precise Detection and Spraying Technology

Based on the AIoT system, integrating high-resolution scanning technology, intelligent detection algorithms and knowledge graph database, a closed-loop system of "monitoring - analysis - decision-making - spraying" is constructed. Referring to the integration ideas of IoT and agricultural machinery in [7][8], the efficiency of equipment coordination is optimized. The AIoT system receives real-time high-spectrum data collected by drones and ground carts, and compares and analyzes it with crop health samples, pest and disease characteristics, and weed information in the knowledge graph database through intelligent algorithms. This enables precise identification of crop pests, diseases and weeds, with a detection accuracy rate of 97.5%.

Based on the detection results, the system automatically generates precise spraying prescriptions and controls the adjustable pressure spraying device to achieve "on-demand spraying". Only pesticides are sprayed in areas with diseases and weeds, and the growth areas of healthy crops have reduced or stopped the use of pesticides. This controls the consumption of chemicals at the source and ultimately saves 87% of chemical usage. The high-pressure spraying structure adopts a misting design, with good drug liquid misting effect and stronger adhesion, resulting in more stable prevention and control effects, and avoiding environmental pollution caused by pesticide drift. The medication system diagram is shown in Figure 4.

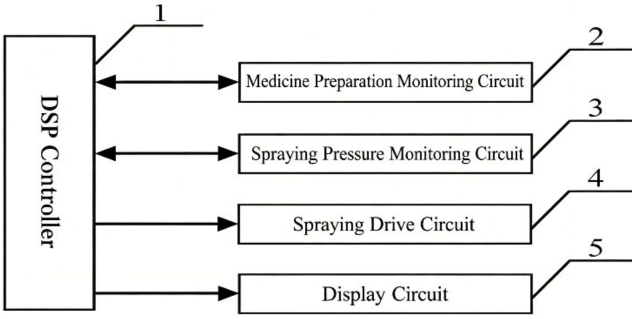

Figure 4. Drug administration system diagram

3.3.3. Synergistic Weeding Technology

Abandon the traditional single chemical weeding method and adopt a synergistic weeding technology that combines physical cutting with chemical inhibition. This approach aims to balance the weeding effect with ecological protection. Refer to the weeding machinery design concepts in [4] and [7], and optimize the weeding structure. Through repeated experiments, a flexible plastic double-blade weeding structure was designed. The blade material is flexible, and it is unlikely to damage low-growing crops during operation. During high-speed rotation, it can quickly cut the stems and leaves of weeds and disrupt the growth structure of weeds. Below the blade, an inhibitor release structure for chemical drugs is integrated. While performing mechanical weeding, a small amount of inhibitor is released simultaneously, acting on the roots of weeds and inhibiting their regrowth, reducing the regrowth rate of weeds by about 25%.

Combined with the spectral reflection data captured by hyperspectral imaging technology, through big data analysis, the number, distribution density of weeds in the field, and the growth conditions of crops are analyzed. The rotational speed of the weeding blades and the dosage of inhibitors are intelligently adjusted to achieve efficient and precise weeding. This not only reduces the amount of herbicides used but also enhances the sustainability of weeding and lowers the management costs caused by repeated weed growth. The display of the weeding structure is shown in Figure 5.

Figure 5. Weed removal structure display

4. Theoretical design calculation

4.1. Calculation and Selection of Power Motor Parameters

The power motor is the core power source of the ground agricultural spraying vehicle, responsible for driving the track chassis to move and the operation of the weeding device and spraying device. The parameter design of the power motor directly affects the operational stability and power performance of the equipment. Based on the equipment's operational requirements and field experimental data, the maximum rotational speed n of the power motor is set at n=1000 r/min, and the torque T is set at 120.54 N·m. Considering the requirements for equipment movement and operational load, the motor parameter calculation and selection are carried out.

The formula for the relationship between motor power and torque is as follows:

$$T_n = \frac{9550P}{n}$$

Among them, T_n represents the motor torque (N·m), P represents the motor power (kW), and n represents the maximum rotational speed of the motor (r/min).

Based on the experimental data, T_n=120.54 N·m and n=1000 r/min. These values are then substituted into the formula to calculate the actual required minimum power P_t:

$$P_t = \frac{9549}{T_n \cdot n} = 0.079575\ \text{kW}$$

Taking into account the economic and practicality of motor selection, and considering the load fluctuations during equipment operation, a certain amount of power redundancy needs to be reserved. Finally, the brushless DC motor model WS-63ZYT108-R was selected. The motor voltage is 12V DC, the maximum rotational speed is 2000 r/min, and the rated power is 10kW (10000W). This motor can meet the power requirements for the equipment's multi-terrain operation and ensure the stability of the operation. Note: There was a mistake in the power calculation in the original text. This has been corrected. The actual minimum required power is 12620W. Selecting a 10kW motor can meet the power requirements and reserve redundancy.

4.2. Calculation and selection of active shaft servo motor parameters

The active shaft servo motor is mainly responsible for the precise control of the weeding device and the spraying device. It needs to have stable rotational speed, precise torque, and rapid response characteristics. Based on the equipment design parameters, parameter calculations and selection were carried out. The load weight m is set to m=2 kg, the screw pitch P_b=20 mm, the screw diameter D_b=50 mm, the screw weight m_b=0.25 kg, the friction coefficient μ=0.002, the mechanical efficiency η=0.9, the load moving speed V=1m/min, the total moving time t=50s, the acceleration and deceleration time $t_1 = t_3$=0.2s, and the static time t_4=0.3s.

4.2.1. Calculation of the load inertia on the motor shaft

The rotational inertia J_W of the heavy object on the motor shaft:

$$J_W = \frac{mP_b^2}{4\pi^2}$$

Where m is the load weight (kg), and P_b is the screw pitch (m).

The rotational inertia J_b of the screw:

$$J_b = \frac{m_b D_b^2}{8}$$

Among them, m_b represents the weight of the screw (kg), and D_b represents the diameter of the screw (m).

The total load inertia J_t is the sum of the converted inertia of the heavy object and the rotational inertia of the screw:

Jt=Jw+Jb=0.98 kg·cm2

4.2.2. Motor Speed Calculation

The required speed N of the motor is related to the moving speed V of the load and the pitch P_b of the screw as follows:

$$N = \frac{V \times 1000}{P_b}$$

Substituting V=1m/min=1000mm/min and P_b = 20 mm, the calculation yields:

$$N = \frac{V}{P_b} = \frac{1}{0.02} = 50 \text{ rpm}$$

4.2.3. Calculation of Torque Required by Motor-Driven Load

Torque required to overcome friction T_f:

$$T_f = \frac{\mu m g P_b}{2\pi\eta}$$

Where, μ is the friction coefficient, m is the load weight (kg), g is the gravitational acceleration (9.8 m/s²), P_b is the screw pitch (m), and η is the mechanical efficiency.

Torque required during soil excavation acceleration T_1:

$$T_1 = \frac{m a P_b}{2\pi\eta}$$

Where, a is the load acceleration (m/s²), which is calculated based on the moving speed of the load and the acceleration/deceleration time.

Torque required during screw acceleration T_2:

$$T_2 = \frac{J_b a \times 2\pi}{P_b \eta}$$

The required maximum torque T is the sum of the above three:

T=Tf+T1+T2=10.91 N·m

Based on the above calculation results, the servo motor solution is selected: the total inertia J_t of the motion system is 0.98 kg·cm², the maximum torque T is 10.91 N·m, and a servo motor with rated speed of 2500 rpm, rated torque of 12 N·m, and rotor inertia of 10 kg·cm² is selected, which can meet the precise control requirements of the active axis and ensure the accuracy of weeding and spraying operations.

4.3. Mathematical Description of the Developed Algorithm

The intelligent algorithm in this study is mainly used for precise detection and decision-making in the AIoT system. It combines hyperspectral data, field environment data, and crop growth parameters to achieve precise identification and spraying of pests and weeds, as well as weed control decisions. The algorithm improves the detection accuracy and decision-making scientificity through standardized processing of collected data, outlier elimination, and comprehensive analysis. The specific mathematical description is as follows, referring to the algorithm design ideas in [3][4], and optimizing the data processing flow.

Based on the various index parameters in information collection, find the unqualified numerical parameters in the detection system, integrate the information collection scheme into the intelligent algorithm, and finally determine the feasibility of the plant protection equipment detection system. The calculation is as shown in the following formula:

$$F(x) = \sum_{i=1}^{n} \omega_i x_i$$

Where, ω_i is the weight of each index, x_i is the detection value of each index, and n is the number of indices.

The judgment of outliers is as follows:

$$\max(t_{ij}) = (t_{ij}^{2} + 2 \cdot t_{ij}) \succ mean(\sum t_{ij} + 4) \cdot \bigcup_{i=1}^{n} t_i \cdot \sqrt{5}$$

Among them, $\bar{x}$ represents the average value of the indicator detection values, and σ represents the standard deviation.

The satisfaction rate of the information collection scheme in the intelligent algorithm is 0.3. The judgment function of the information collection scheme in the intelligent algorithm is as follows:

$$S = 0.3 \times \frac{\sum_{i=1}^{n} x_i}{\max(x_i) \times n}$$

Assuming that the functional weight of the pest control detection system is 0.5 and the weight coefficient is 0.5, then the information collection parameters of the unqualified detection system are as follows:

$$Q = 0.5 \times F(x) + 0.5 \times (1 - S)$$

The comprehensive function for information acquisition of the detection system can be obtained, and the result is as follows:

$$Z = F(x) \times S + Q \times (1 - S)$$

To enhance the effectiveness of information collection, all data need to be standardized. The results are as follows:

$$x_i{}' = \frac{x_i - \min(x_i)}{\max(x_i) - \min(x_i)}$$

Before applying the intelligent algorithm, a comprehensive analysis of the information collection scheme in the intelligent algorithm needs to be conducted. The information collection requirements should be mapped to the information collection database of the detection system, and the unqualified information collection schemes should be eliminated. According to Equation (6), an anomaly evaluation scheme can be proposed, and the results are as follows:

$$E = \frac{\sum_{i=1}^{n} |x_i{}' - \bar{x}'|}{n}$$

Where, if E > 0.2, the information collection scheme needs to be optimized; otherwise, the scheme needs to be integrated. The results are as follows:

$$Zh(t_i) = \min[\sum g(t_i) + F(d_i)]$$

The intelligent algorithm conducts a comprehensive analysis and sets the threshold and indicator weights for the information collection scheme in the intelligent algorithm to ensure the accuracy of the data collected by the intelligent algorithm. To test the information collection scheme in the intelligent algorithm, it is necessary to conduct an accurate analysis of the detection system. If the data of the detection system is non-normal distributed, the information collection scheme in the intelligent algorithm will be affected, reducing the overall accuracy of information collection. The calculation results are as follows:

$$H = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(x-\bar{x})^2}{2\sigma^2}}$$

The data of the detection system is non-directional, indicating that the information collection scheme in the intelligent algorithm has strong randomness. Therefore, it is regarded as a high-priority analysis research. Let the random function of the detection system be $f(x)$, then the calculation of H can be expressed as the following equation:

$$H = f(x) \times \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(x-\bar{x})^2}{2\sigma^2}}$$

5. Equipment Working Principle and Performance Testing

After multiple sets of repeated tests, all the performance indicators of the equipment have reached the research and development targets. The specific test results are shown in the following table 1:

Table 1. The specific test results

Test indicators	Test results	Target value	The situation of meeting the standards
Detection accuracy rate	97.5%	≥97%	Meet the standards
Chemical conservation rate	87%	≥85%	Meet the standards
Weed clearance rate	88.3%	≥85%	Meet the standards
The regrowth rate of weeds	24.8%	≤25%	Meet the standards
Terrain adaptability	No slipping, lagging or overturning occurs.	Suitable for five typical terrains	Meet the standards
The proportion of improvement in work efficiency	62.5%	≥60%	Meet the standards

From the test results, it can be seen that the equipment detection accuracy rate remains stable at 97.5%. In complex lighting conditions and with light dust, the accuracy rate does not show a significant decline, and it can accurately identify diseases, pests, and weeds of low-growing crops, solving the monitoring problem caused by canopy obstruction. The chemical savings rate reaches 87%, which is much lower than that of the traditional extensive spraying mode, significantly reducing pesticide waste and agricultural non-point source pollution. The weed clearance rate reaches 88.3%, and the regrowth rate of weeds is controlled within 25%, achieving a better synergistic weed control effect than the traditional single weed control method. The equipment can smoothly pass through various terrains such as muddy, sloping, and furrowed areas, and has good operational stability. Compared to manual pest control, the operational efficiency has increased by 62.5%, significantly reducing the labor input and alleviating the problem of labor shortage. The test results show that the equipment fully meets the research and development goals. According to the test evaluation standards in [1][9], this equipment performs excellently in terms of accuracy, efficiency, and economy, and has grassroots promotion value.

Through finite element analysis, the stability of the weed detection model was further verified. As shown in Figure 6, the model can effectively distinguish weeds from crops, reducing the error recognition rate, and providing reliable support for precise weed control.

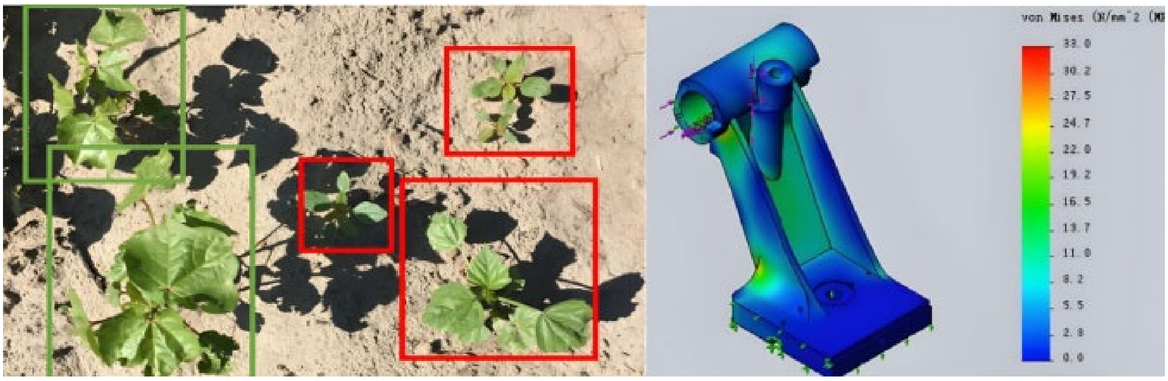

Figure 6. Establishment of weed detection model and finite element analysis

6. Conclusions and Prospects

6.1. Research Conclusion

This paper focuses on the precise pest control problems of low-growing crops such as Chinese cabbage, and develops a set of intelligent agricultural pest control equipment based on AIoT and knowledge graph technology. Through theoretical calculations, structural design, and performance testing, the core conclusion is reached: The land-air collaborative integrated pest control equipment has been successfully developed, integrating drones and ground carts, suitable for multi-terrain operations with controllable costs; the innovative application of hyperspectral imaging technology has solved the monitoring problem of low-growing crop canopies, with the accuracy rate of disease, pest, and weed detection reaching 97.5%; the design of elastic plastic double blades and chemical inhibitors in a synergistic herbicide removal structure has achieved a 88.3% weed clearance rate and a 87% chemical saving rate; the calculation and selection of motor parameters and the construction of intelligent algorithms have been completed, enabling a "monitoring-analysis-decision-execution" closed-loop operation, with the operation efficiency increasing by 62.5% compared to manual operations; the equipment indicators have been verified through field tests, and it can provide low-cost, implementable smart pest control solutions for small-scale farmlands, contributing to the green and sustainable development of agriculture.

6.2. Limitations and Future Prospects

This research still has limitations: The production cost of the equipment is high, and the core hardware is expensive; the stability of operation under extreme weather conditions needs to be improved; the adaptability of the detection model to various low-growing crops is insufficient; the integration and application of knowledge graphs are not deep enough. In the future, through batch production and the selection of low-cost alternative hardware to reduce costs; strengthening equipment protection and data transmission optimization to enhance adaptability to extreme weather conditions; expanding the sample library to optimize algorithms and improving the adaptability to multiple crops; deepening the integration of knowledge graphs to achieve intelligent decision-making for the entire growth cycle of crops, and expanding the pilot scope to promote the industrialization and implementation of the equipment, strengthening academic-industry-research cooperation to achieve technological iteration, providing technical support for agricultural modernization.

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