World Journal of Engineering Research
Print ISSN: 2959-9865
Online ISSN: 2959-9873
DOI: https://doi.org/10.61784/wjer3087

GUANGYUE MOJIE: AN INTELLIGENT AGRICULTURAL MANAGEMENT DEVICE BASED ON THE STM32 MICROCONTROLLER

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Abstract: Addressing the limitations of traditional greenhouse light management—reliance on weather, high energy consumption of artificial lighting, and inflexible spectra—this paper presents an intelligent agricultural device named "Light Film Realm" based on an STM32 microcontroller. Its core innovation is an automatically switchable intelligent film system that dynamically filters specific spectra according to crop needs, enabling precise regulation of optimal photosynthetic light combinations. The system integrates STM32 with multiple sensors (light intensity, temperature, humidity) and a 5G module for real-time data collection and cloud transmission. A remote monitoring platform, including WeChat mini-programs and web interfaces, combines local automatic control with remote manual intervention for intelligent human-machine-environment interaction. At the server end, machine learning algorithms analyze the collected data to dynamically optimize light regulation strategies and provide scientific decision support. Additionally, an online-merge-offline (OMO) business model was designed, encompassing online product display and technical consultation alongside offline installation, maintenance, and after-sales service, facilitating market promotion and technology transfer. Experimental results demonstrate the system's superior performance in enhancing light regulation precision, reducing energy consumption, and improving user interaction experience, offering a viable pathway toward more intelligent, precise, and sustainable agricultural production.
Keywords: Intelligent agriculture; STM32; Intelligent light film; Light control; Internet of things

1 INTRODUCTION

With global population growth and increasing strain on arable land resources, traditional agricultural production methods are struggling to meet the growing demand for agricultural products while adhering to sustainability requirements. Smart agriculture, as a product of the deep integration of information technology, biotechnology, and environmental science, is emerging as a key pathway for the modernization and transformation of agriculture. During plant growth, factors such as light, temperature, soil moisture, and carbon dioxide concentration all exert influence[1-4]. As the core energy source for plant growth, light directly affects crop yield and quality. However, traditional greenhouses exhibit significant limitations in light environment management: natural light sources are constrained by weather conditions, artificial lighting for supplementation consumes substantial energy, and achieving precise regulation of light quality remains difficult[5].
The "Light Film Realm" project was developed with the aim of creating a microcontroller-based intelligent agricultural management device that achieves precise regulation of the crop light environment by intelligently controlling the spectral transmittance characteristics of greenhouse films and artificial light sources. This device can automatically switch between natural and artificial light according to the crop type and growth stage. It filters out ineffective or harmful spectra from natural light while retaining photosynthetically active radiation (PAR) bands such as red and blue light. This approach enhances photosynthetic efficiency while conserving energy, thereby promoting high crop yield and quality. Furthermore, the integrated mobile and web-based applications enable farmers to monitor environmental data and remotely control equipment anytime and anywhere, facilitating intelligent and transparent agricultural production. From a project evaluation perspective, this device offers multifaceted advantages: firstly, it improves crop growth rate and yield, directly enhancing economic benefits through an optimized light environment; secondly, it promotes green and sustainable development by reducing reliance on fertilizers and pesticides, thus lowering agricultural non-point source pollution; thirdly, it improves the quality of agricultural products, enhancing market competitiveness; fourthly, it saves energy by increasing the utilization efficiency of solar energy, thereby reducing production costs; and fifthly, it drives the agricultural modernization process by providing farmers with a convenient and efficient production management tool.
From a market demand perspective, the acceleration of agricultural modernization has led to a growing need among farmers for efficient and environmentally friendly production methods [6]. From a technological development standpoint, the integration of new materials, novel processes, with the Internet of Things (IoT) and big data provides robust support for innovation in this sector [7]. From a policy support viewpoint, strong national policies offer a solid foundation for the project's research, development, and promotion. In recent years, the "No. 1 Central Document" has repeatedly emphasized advancing agricultural and rural informatization and the development of smart agriculture. In 2024, it explicitly outlined key tasks such as "continuing to implement the Digital Rural Development Initiative" and

"developing smart agriculture" [8]. The application of intelligent photoselective films holds multiple benefits: by optimizing the light environment, it can enhance crop yield and quality, promote photosynthesis, and improve crop stress resistance[9]. Concurrently, it can conserve energy, reduce production costs, and facilitate the transformation of agricultural production towards intelligence and precision, aligning closely with the strategies of rural revitalization and agricultural modernization. Based on this context, this study proposes "Light Film Realm," an intelligent agricultural management device based on an STM32 microcontroller [10]. It aims to achieve precise monitoring and remote management of crop growth through intelligent regulation of the greenhouse light environment, thereby offering a viable solution for enhancing agricultural productivity and promoting the intelligent development of agriculture.

2 TARGET

This project aims to design and implement an intelligent agricultural management device called "Light Film Realm" based on an STM32 microcontroller. By intelligently regulating the light environment within greenhouses, it achieves precise monitoring and remote management of the crop growth process, thereby enhancing agricultural production efficiency, reducing labor costs, and promoting the intelligent development of agriculture. The core objective of the project is to develop an intelligent film system capable of automatically switching between natural and artificial light in response to environmental changes. This system can filter specific spectra from external light sources according to crop growth requirements, providing an optimal spectral composition for plant photosynthesis. Concurrently, by integrating an STM32 microcontroller with various environmental sensors, it enables real-time monitoring and data acquisition of parameters such as light intensity, temperature, and humidity inside the greenhouse. Figure 1 illustrates the actual environment within the greenhouse under natural lighting conditions, directly reflecting the state of natural light in practical applications and its impact on crop growth.

Figure 1 Real-World Environment Of Natural Lighting
Source: Internet platform

Figure 2 illustrates the actual scene within the greenhouse under artificial lighting conditions, reflecting the application scenarios of artificial light supplementation during nighttime or cloudy/rainy weather and its supplementary role in crop growth.

Figure 2 Real-World Environment of Artificial Lighting
Source: Internet platform

Building upon this foundation, the project will establish a comprehensive remote monitoring and control system, encompassing a WeChat mini-program and a web-based application. This will enable users to view environmental data and video surveillance feeds, as well as remotely control actuators such as lighting equipment and film switching devices within the greenhouse, from any location at any time, thereby achieving intelligent human-machine-environment interaction. Through server-side analysis and modeling of the collected data, combined with machine learning algorithms, the system will progressively realize automated optimization of light regulation. This provides scientific decision support for crop growth, ultimately enhancing both yield and quality.

Furthermore, the project is dedicated to exploring market-oriented pathways for smart agricultural equipment. By integrating online and offline service models, it aims to promote the practical application of intelligent agricultural technologies and enhance farmers' acceptance and capacity to utilize modern techniques, thereby providing a viable solution for advancing intelligent and precision agriculture in China.

3 RSEARCH METHODS

3.1 System Overall Architecture

This project adopts a technical route of software-hardware collaboration and cloud-edge integration to construct an intelligent agricultural management system based on the STM32 microcontroller. The overall system architecture is divided into four layers: the perception layer, the network layer, the platform layer, and the application layer. The perception layer, centered around the STM32, integrates various sensors such as light, temperature and humidity, and plant physiological indicators. It is responsible for real-time collection of environmental data, including light intensity, temperature and humidity, soil conditions, and plant physiological parameters. The network layer employs 5G communication modules combined with a distributed structural design. After data dimensionality reduction is completed at the sensor end, the data is clustered and transmitted to the cloud via an intermediate processor, ensuring the efficiency and stability of data transmission. The platform layer involves the construction of cloud servers, the development of backend data processing logic, and the integration of machine learning algorithms for regression, classification, and clustering analysis of the data, thereby enabling dynamic optimization of control models. The application layer, through WeChat mini-programs and web interfaces, provides users with data visualization, remote control, and intelligent early warning functionalities.

The system's core control unit utilizes an industrial-grade microcontroller, which offers advantages such as low power consumption, high performance, and rich peripheral interfaces. This enables it to meet the real-time requirements of multi-sensor data acquisition, preliminary data processing, and actuator control. Figure 3 shows a physical diagram of the STM32-based sensing device, illustrating its core control role in the hardware design. The backend server is built using real-time communication technology that supports high-concurrency connections, enabling it to simultaneously handle data reporting from multiple greenhouse intermediate processors and user requests. Mainstream data analysis tools are employed for data processing and modeling.

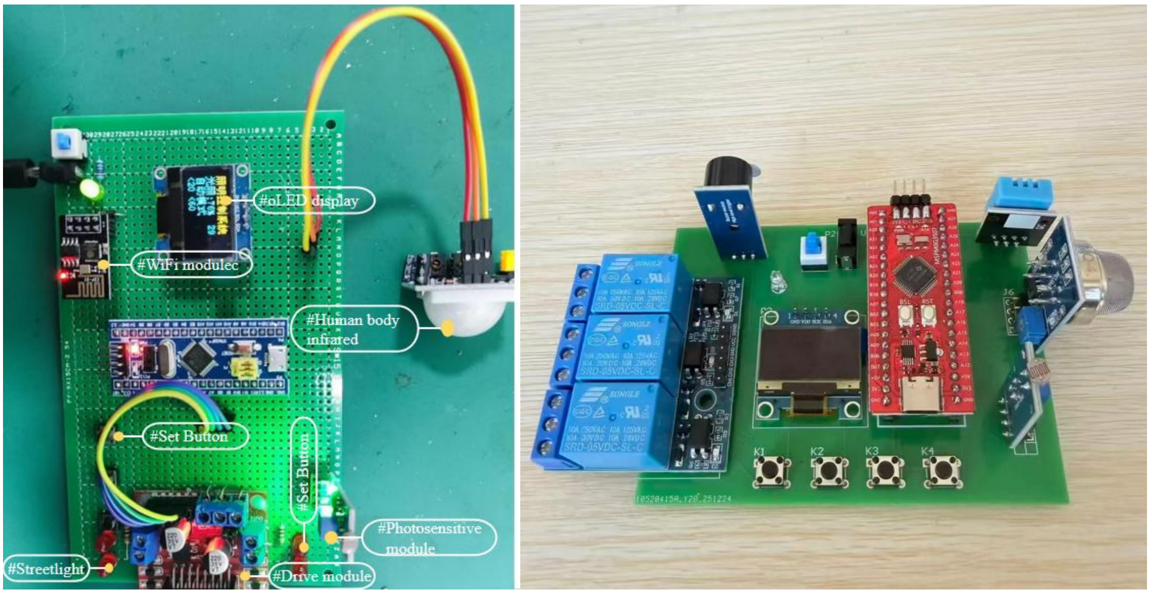

Figure 3 STM32-Based Sensor Device

Figure 4 illustrates the interaction relationships among the perception layer, network layer, platform layer, and application layer within the system, and clarifies the data flow and control logic between these layers.

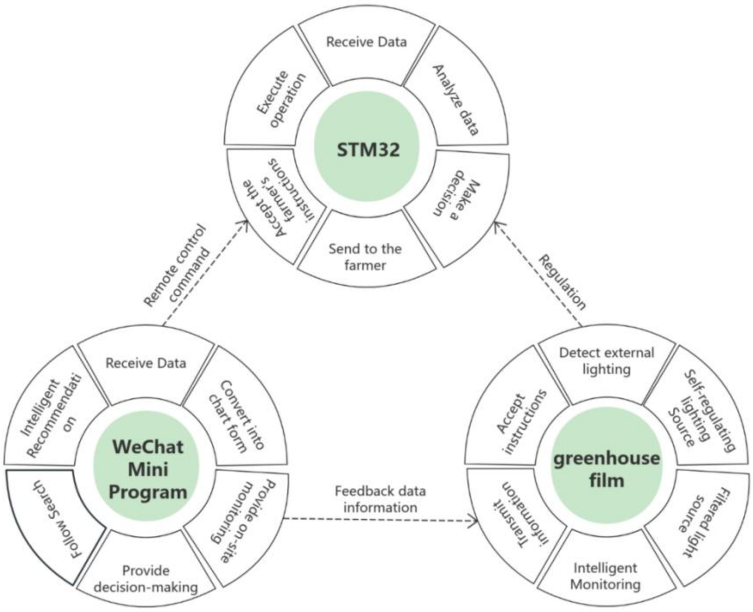

Figure 4 Interaction Diagram of the Main Modules

3.2 Hardware Design and Sensor Networks

In terms of hardware design, multiple sensor nodes are deployed within each greenhouse. Each node, centered around a microcontroller, is connected to light sensors, temperature and humidity sensors, soil moisture sensors, and plant physiological parameter sensors (e.g., for chlorophyll content, nitrogen content, etc.). The sensors convert the collected analog signals into digital signals, which are then subjected to preliminary processing and packaging by the microcontroller. Subsequently, the data is transmitted via a wireless communication module to a local intermediate processor or uploaded directly to the cloud server. This design ensures the accuracy and real-time performance of data acquisition.

To address the multi-dimensional and heterogeneous nature of agricultural production environment parameters, the system adopts a distributed data acquisition architecture. Multiple low-level sensor nodes are deployed at different locations within a greenhouse, each responsible for data collection and preliminary dimensionality reduction processing. An intermediate processor is installed per greenhouse, tasked with aggregating data from all low-level nodes within that greenhouse, performing data cleaning, feature extraction, and clustering fusion. The intermediate processor then uploads the processed data to the cloud server via a wireless network. This architecture effectively reduces network transmission burden while improving data processing efficiency and system reliability.

The effector section comprises actuator modules including a film deployment controller, artificial light regulators, and irrigation valves. Three control modes are supported: local automatic mode, which operates based on fixed programs preset in the low-level processor to automatically activate artificial light supplementation at night or on cloudy/rainy days; intelligent decision-making mode, which receives control instructions issued by the intelligent model on the server to dynamically adjust film color and light source spectra; and remote manual mode, which allows users to manually intervene via the mobile or web application to execute specific operations. The film deployment controller utilizes a motor-driven roller mechanism to quickly switch between film rolls with different spectral characteristics according to commands, thereby achieving spectral filtering of natural light and supplementation with artificial light. The artificial light source employs a multi-band LED array, in which the intensity of light at different wavelengths can be independently controlled. Figure 5 illustrates the structural composition and execution module layout of this fully automatic control system, demonstrating its operational feasibility and integration level in practical deployment.

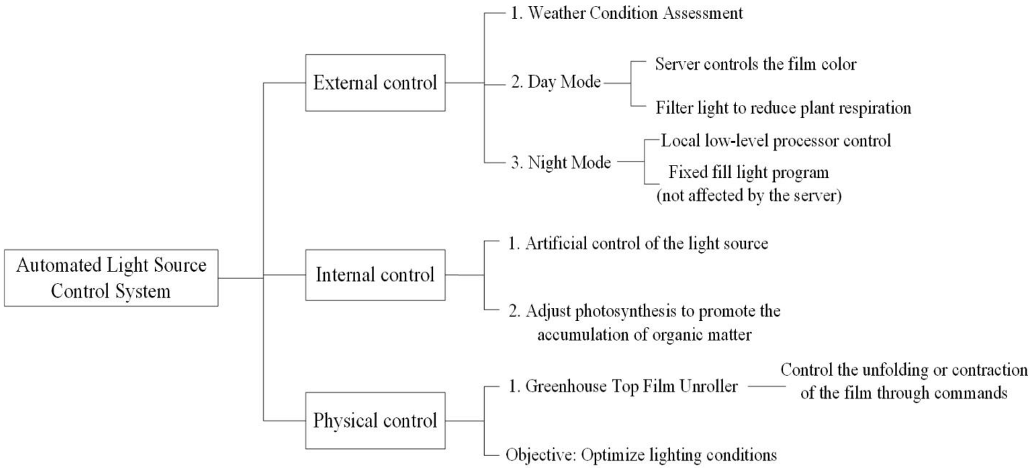

Figure 5 Light Film Realm Fully Automatic Control System

3.3 Software Platform and Intelligent Decision-Making Algorithms

The backend server is built using mainstream backend development technologies, employing data analysis and machine learning tools for data processing and modeling. Upon reception, data is first stored in a time-series database, which then triggers the data analysis workflow. To achieve adaptive and precise control, the system constructs a dynamic modeling mechanism combining unsupervised and supervised learning. Initially, historical environmental data and crop growth data are collected. Clustering algorithms are used to segment growth stages and environmental conditions, establishing a foundational decision model. Upon receiving each new set of valid data, the system merges it with historical data, re-performs cluster analysis and feature extraction, and updates the model parameters. When the next data cycle arrives, the system makes predictions and judgments based on the latest model, calculates the optimal light regulation strategy, and sends control commands to the effectors. Finally, the crop response data following the actual regulation serves as feedback to evaluate the model's fit and record deviations, which are used for subsequent model iteration and optimization. This mechanism enables the model to continuously self-improve as data accumulates, adapting to the differentiated requirements of various crop species and regional climates.

In terms of application development, the mobile and web applications adopt a front-end and back-end separation architecture. The mobile application, built on mainstream mobile development platforms, implements functionalities such as user login, device binding, real-time data monitoring, historical data query, remote control, and video surveillance. The web application provides more comprehensive management features, including multi-greenhouse overview, data analysis reports, and user permission management. Data interaction between the front-end and back-end is conducted through standard communication protocols, ensuring real-time performance and reliability. Figure 6 illustrates the complete process of the system, from data collection and model updating to the issuance of control commands, clarifying the logical relationships and data flow among each stage.

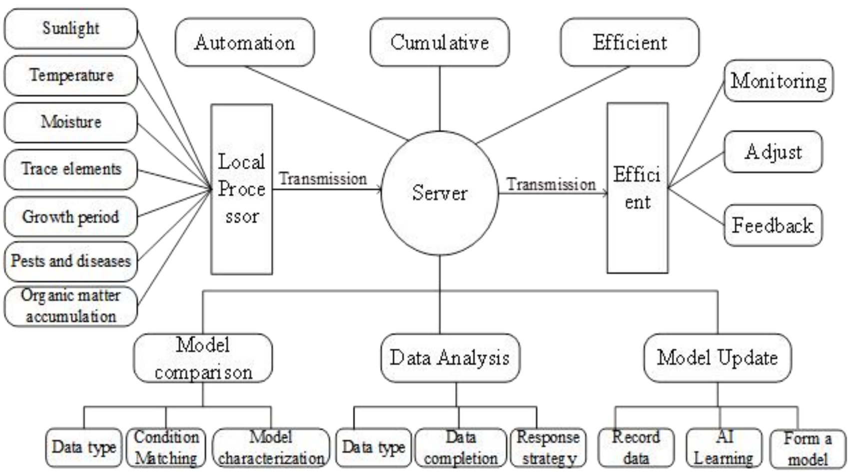

Figure 6 Process Model Diagram

3.4 Business Model and Operational Mechanism

The project adopts an online-merge-offline business model, aiming to provide users with one-stop services encompassing product purchase, usage guidance, and after-sales support. The online platform consists of an official website with core functions focused on product display, technical Q&A, and online sales. It showcases practical application cases through graphics, text, and videos, and supports functionalities such as online consultation, technical inquiries, product ordering, and payment. Simultaneously, the website publishes popular science articles on smart agriculture and usage tutorials to enhance user engagement.

In terms of the offline service network, the project establishes cooperative relationships with local agricultural enterprises and cooperatives, setting up regional service outlets responsible for equipment installation and commissioning, on-site fault diagnosis and repair, and user training. For repairable equipment issues, technical personnel perform on-site repairs; for irreparable problems, the device is directly replaced with new equipment to safeguard user interests. The profit model primarily generates revenue through hardware equipment sales, supplemented by diversified income sources such as value-added data services (e.g., annual data analysis reports, planting advice subscriptions), technical training services, and advertising collaborations. In the initial phase, the project will focus on key agricultural production areas, driving market adoption through pilot demonstrations to gradually establish brand recognition.

To facilitate the translation of technological achievements, the project has designed an online-merge-offline operational model. The online platform features an official website for product display, online sales, and technical consultation, providing product details and practical application cases. Offline, the project collaborates with local enterprises to establish a service network, offering after-sales support including equipment installation, fault repair, and regular inspections, with a rapid replacement process initiated for issues that cannot be resolved on-site. This model not only expands market channels but also strengthens user trust, laying a practical foundation for the large-scale application of smart agricultural equipment.

4 CONCLUSION

This study successfully designed and implemented an intelligent agricultural management device named "Guangyue Mojie" based on the STM32 microcontroller. By adopting a technical route of software-hardware collaboration and cloud-edge integration, a comprehensive system architecture spanning the perception layer, network layer, platform layer, and application layer was constructed. The core innovation of the project lies in the development of an intelligent film system capable of automatically switching between natural and artificial light. This system can filter specific colors of light according to crop growth requirements, providing an optimal spectral combination. Concurrently, it integrates multiple environmental sensors to achieve real-time monitoring and data collection of parameters such as greenhouse light intensity, temperature, and humidity.

In terms of functional implementation, the project constructed a remote monitoring platform integrating a WeChat mini-program and a web interface. Users can view environmental data and video footage at any time, as well as remotely control lighting equipment and film switching devices, thereby achieving intelligent human-machine-environment interaction. The server end integrates machine learning algorithms, progressively realizing adaptive decision-making for light regulation through data modeling and dynamic optimization, providing a scientific basis for crop growth. Furthermore, the project designed an online-merge-offline operational model: an online platform was established for product display and sales, while an offline service network was created to provide installation and maintenance support. This lays the foundation for the translation of technological achievements and market promotion.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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