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An Investigation into the Intelligent Ecological Animal Husbandry Based on Embedded Systems

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Abstract: In response to China's imperative for sustainable livestock development and socioeconomic progress, the concurrent advancement of ecological and smart livestock farming is being promoted. The realization of a smart ecological livestock farming model necessitates the intelligent evolution of both equipment and management practices, alongside the application of computer technologies such as big data and cloud computing. However, current systems suffer from poor interoperability and compatibility, which impedes effective data integration and sharing. Furthermore, the existing technological solutions lack adaptability to regional variations, resulting in inadequate technical applicability and suboptimal implementation outcomes. This paper employs literature reviews and technology assessment methodologies to explore the developmental pathways and technological implementations of smart ecological livestock farming. A comprehensive smart ecological livestock farming system based on embedded technology, such as Raspberry Pi and STM32, is designed to facilitate the advancement of smart ecological livestock farming. The conclusion drawn is that smart ecological livestock farming represents an inevitable trajectory for the modernization of the livestock industry.

Keywords: Embedded systems, smart livestock farming, ecological engineering, automation technology, intelligent equipment

1. Introduction

Ecological livestock farming, an ecological concept, represents the practical application of ecological engineering within livestock production. Achieving ecological livestock farming requires three key elements: ecological equilibrium and sustainable development, animal welfare, and efficient production with stringent quality control, all aimed at securing long-term, stable ecological and economic benefits. Smart livestock farming, a novel paradigm in livestock development, leverages modern information technology, employing intelligent devices and systems for real-time monitoring and precise control across all stages of animal husbandry. Traditional livestock practices alone are insufficient for achieving ecological sustainability, often resulting in significant resource consumption and reduced efficiency. Consequently, the trajectory of smart ecological livestock farming aligns with the trends of modern agricultural technological innovation, representing a judicious approach to achieving sustainable livestock development. China's push for specialized, intensive, and intelligent livestock farming has spurred the emergence of three smart ecological livestock farming models: the intelligent development of equipment, the smart advancement of management practices, and the widespread application of big data and cloud computing. However, a

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gap exists between technological aspirations and practical implementation, with insufficient interconnectivity and compatibility among these models. Overcoming these challenges is crucial to transforming livestock farming toward smart, ecological practices [1].

This paper offers a systematic review and assessment of intelligent ecological livestock farming research, proposing a comprehensive framework for integrating smart agriculture with ecological practices. The findings aim to provide solutions for ecological challenges in livestock production, thereby promoting efficient, environmentally sound and sustainable development within the sector. The proposed design involves leveraging advanced embedded systems to construct an intelligent, automated and data-driven integrated livestock management system, with the ultimate goal of significantly enhancing production efficiency, resource utilization and ecological sustainability.

The investigation into intelligent ecological livestock farming holds substantial theoretical and practical significance. It facilitates the transformation and advancement of livestock farming by incorporating advanced technologies. This approach enhances resource utilization efficiency, mitigates environmental pollution, and improves animal health and welfare. It also ensures food safety, addresses labor shortages, and stimulates rural economic growth, thereby supporting global sustainable development objectives. Furthermore, this research provides a scientific foundation for policy formulation, promotes technological innovation and industrial integration, and offers robust support for the sustainable development of livestock farming and the harmonious coexistence of humans and nature.

2. Development feasibility

2.1. Development needs

2.1.1. Governmental policies and strategies

The Ministry of Agriculture and Rural Affairs of China's "Guiding Opinions on Vigorously Developing Smart Agriculture" and the "National Smart Agriculture Action Plan (2024-2028)" explicitly state the government's need to guide the development of intelligent large-scale farming. This will be achieved through the integration of technologies such as precise environmental control, growth information monitoring, and intelligent diagnosis and prevention of diseases, as well as the promotion of smart equipment like precision feeding systems. The Chinese government has placed significant emphasis on the revitalization of agriculture and rural areas, encouraging livestock enterprises to adopt information management systems to facilitate the industry's progression towards specialization, intensification, and intelligentization. Furthermore, the Ministry of Agriculture and Rural Affairs of China consistently supports the research and application of livestock breeding equipment, establishing key laboratories, fully mechanized research bases, and teams of scientific experts, such as the "Livestock and Poultry Breeding Engineering Professional Group" and the "Straw Treatment and Feed Mechanization Professional Group." These efforts actively promote the research and development of livestock breeding equipment within relevant national research and development projects. In the utilization of straw for feed, the government has initiated the "Creation and Application of Intelligent Operation Equipment for the Entire Process of Major Feed Production" project, focusing on the development of intelligent equipment suitable for efficient and high-quality operations in key production stages, including planting, harvesting, and storage and transportation, to establish a fully intelligent equipment operation system for feed production. In the realm of livestock management, the government has initiated the "R&D Project on Large-Scale Intelligent Breeding Technology and Equipment for Beef Cattle." This project concentrates on the development of intelligent equipment, specifically targeting high-efficiency beef cattle breeding, precision feeding, health monitoring, and manure removal, aiming to establish an integrated, factory-style confinement

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model encompassing breeding, health, feeding, operation, and management of beef cattle. Concurrently, the Ministry of Agriculture and Rural Affairs is continuously refining the data statistical monitoring system, accelerating the integration of information resources within the livestock industry, and strengthening the information-based construction of livestock production [2].

Furthermore, the 19th National Congress of the Communist Party of China in 2017 first proposed the rural revitalization strategy, which was re-emphasized in the "14th Five-Year Plan" and the long-range objectives for 2035, adopted at the Fifth Plenary Session of the 19th Central Committee in 2020. The plan prioritizes the development of agriculture and rural areas, and comprehensively promotes the rural revitalization strategy. However, traditional livestock farming is an industry characterized by high consumption, high pollution, and low output. The over-exploitation of natural resources and the environmental damage caused by large amounts of waste during livestock and poultry breeding pose a significant threat to the ecological balance of rural areas, making traditional livestock farming the biggest shortcoming in rural ecological revitalization. Rural revitalization requires not only strengthening agriculture and enriching farmers but also beautifying the countryside. Against this backdrop, while vigorously developing the livestock industry to promote the prosperity of rural industries, it is necessary to fundamentally address the damage caused by traditional livestock farming to the ecological environment to achieve an ecologically livable environment [3].

Consequently, the integration of smart technologies with ecological principles in livestock management represents a pivotal strategy for achieving sustainable development within the livestock sector and aligning with national strategic objectives.

2.1.2. Market and societal evolution

The construction and advancement of intelligent ecological livestock farming are crucial for meeting the demands of upgraded consumption patterns. As a critical component of the food production chain, the healthy development of the livestock industry directly impacts the improvement of residents' quality of life and food supply stability. With the advancement of economic society and an increase in residents' income levels, consumer demand for food has shifted from quantity to quality, particularly with higher expectations for the quality, safety, and nutritional value of animal-based foods such as meat, eggs, and dairy products. Intelligent ecological livestock farming, through the introduction of embedded technology and other techniques, enables refined management and intelligent control of the entire livestock production process, thus providing consumers with higher-quality, safer, and traceable animal-based foods.

Furthermore, within the context of a globalized market, the intensification of international trade and the escalating demand for high-quality food products render traditional, extensive livestock farming practices inadequate for navigating the intense competitive pressures. Smart ecological livestock management, facilitated by technological innovation and digital transformation, offers a pathway to significantly enhance enterprise productivity, management efficacy, and product value, thereby bolstering core competitive advantages. For instance, intelligent livestock systems can optimize resource allocation, leading to reduced production costs and improved breeding efficiency. Concurrently, data analytics and market forecasting empower enterprises to better gauge market demands and formulate strategic business plans, thus securing a first-mover advantage. This strategic approach not only aids enterprises in achieving prominence within the domestic market but also elevates their competitiveness in the international arena, facilitating the globalization of China's livestock industry.

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2.1.3. Economic growth

The development of intelligent ecological animal husbandry also significantly contributes to economic growth. The industrial chain of intelligent ecological animal husbandry encompasses numerous processes with a high degree of interconnectedness between different stages. This not only promotes the concurrent development of related industries such as feed, veterinary drugs, and breeding equipment but also indirectly fosters the prosperity of multiple sectors, including food processing, logistics, and marketing. This chain-reaction economic growth model can inject fresh vitality into local economies and correspondingly contribute to the overall economic development of the nation [1].

2.2. Current status and challenges

2.2.1. Current status

The development of smart livestock management is characterized by three primary paradigms: the advancement of intelligent equipment, the enhancement of management practices through smart technologies, and the extensive application of big data and cloud computing.

The integration of smart technologies in livestock management encompasses advancements in feed delivery systems and environmental control systems. Automated feeding has been implemented across various livestock species, including swine, laying hens, broilers, and dairy cattle, through the application of feed delivery systems. These systems enable scheduled and precise feed distribution via equipment management. Environmental control systems, such as ventilation and cooling mechanisms, utilize database-driven controls to regulate temperature and humidity within livestock housing, thereby optimizing the environment for animal growth [4]. Furthermore, waste management systems, manure treatment equipment, and automated egg collection devices are increasingly being adopted in practical livestock operations. The intelligent development of management practices has led to the adoption of management software by large-scale farms and companies. These software solutions incorporate functionalities for personnel management, material flow tracking, consumable management, and financial administration, significantly enhancing operational efficiency.

The application of big data and cloud computing has led to the deployment of data acquisition systems by numerous breeding enterprises, enabling the continuous and large-scale collection of daily production data. Cloud computing facilitates the exploitation of big data potential, primarily through bioinformatics. This process integrates multiple disciplines, including genomics, gene editing, bioinformatics, systems biology, synthetic biology, image recognition, and phenotype prediction, to establish a precise, economical, controllable, and efficient breeding system. Furthermore, biological enterprises, such as vaccine and veterinary companies, leverage big data collection and analysis to understand livestock and poultry farming distribution, and forecast future market trends and industry prospects through big data technologies [5-6].

2.2.2. Challenges

Despite advancements in smart livestock technologies, several challenges hinder their large-scale implementation.

From a technological standpoint, while significant progress has been made in theoretical research and laboratory applications—particularly in intelligent farming, precision feeding, automated environmental control, and disease diagnosis—scaling these technologies for practical use remains challenging. Additionally, the main production entities in China's livestock industry are small and medium-sized farms, whose infrastructure conditions, technical application capabilities, and investment levels vary greatly, which significantly reduces the actual implementation effect of

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advanced technologies. Moreover, there is a disconnect between technology research and development and production practice. Some technical solutions have not fully considered the differences in climate conditions, breeding varieties, and management models in different regions of China, which leads to insufficient technical applicability.

Another critical challenge is the underdeveloped technical promotion and support system. The lack of professional technical guidance and training discourages many farmers from adopting new technologies, resulting in a gap between expected and actual application outcomes. To overcome these challenges, the integration of smart livestock farming and ecological livestock farming should involve interconnected models that leverage their respective strengths to better achieve the goals of ecological livestock farming.

3. Advancements in core technologies

The core technologies currently underpinning smart livestock management encompass embedded systems, big data analytics, artificial intelligence (AI), blockchain technology, cloud computing, 5G communication, robotics, and gene editing/biotechnology. In integrating smart and ecological livestock management, this study prioritizes the application of embedded systems due to their distinct advantages in intelligent ecological agriculture. Embedded systems offer distinct advantages within intelligent ecological agriculture, including real-time data processing, low power consumption, high integration, automated control, high reliability, and cost-effectiveness. These systems facilitate precise monitoring, intelligent decision-making, and automated management. Their environmental adaptability and multi-protocol communication capabilities render them suitable for complex agricultural scenarios, thereby significantly enhancing production efficiency and reducing resource consumption. This approach fosters the transformation of agriculture towards intelligent and sustainable development.

In smart livestock management, the integration of embedded systems with biosensors and wearable devices enables continuous monitoring and anomaly detection of animal physiological indicators. For instance, body temperature is a critical metric for assessing dairy cow health, with a normal range of 37.5–39.5°C; deviations may indicate physiological changes. Consequently, wearable technology for dairy cows facilitates the daily surveillance of estrus cycles and vital signs, including body temperature, activity levels, heart rate, and respiration rate. These physiological parameters are transmitted to a control terminal for processing. Through a gateway connection to a user-end platform, producers can remotely monitor livestock conditions, allowing for timely intervention and improved herd management [7-8].

Current implementations of wearable devices in embedded systems leverage several technologies to enhance the automation, efficiency, and precision of temperature monitoring. These include wireless communication solutions based on the NRF24E1 chip and infrared sensors, a WiFi-based body temperature monitoring system, and a body temperature acquisition system built upon a ZigBee wireless sensor network. Existing optical measurement methods are primarily suited for static detection [9].

4. Proposed solutions

To address the bottlenecks in the promotion of advanced technologies and the technical challenges posed by poor compatibility between devices, this paper proposes an embedded system as a solution. The system aims to overcome the barriers to technology promotion through its advantages in efficient integration and compatibility. The system enables seamless collaboration and data interoperability between devices, providing comprehensive support for the intelligent and ecological transformation of the livestock industry.

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4.1. Design overview

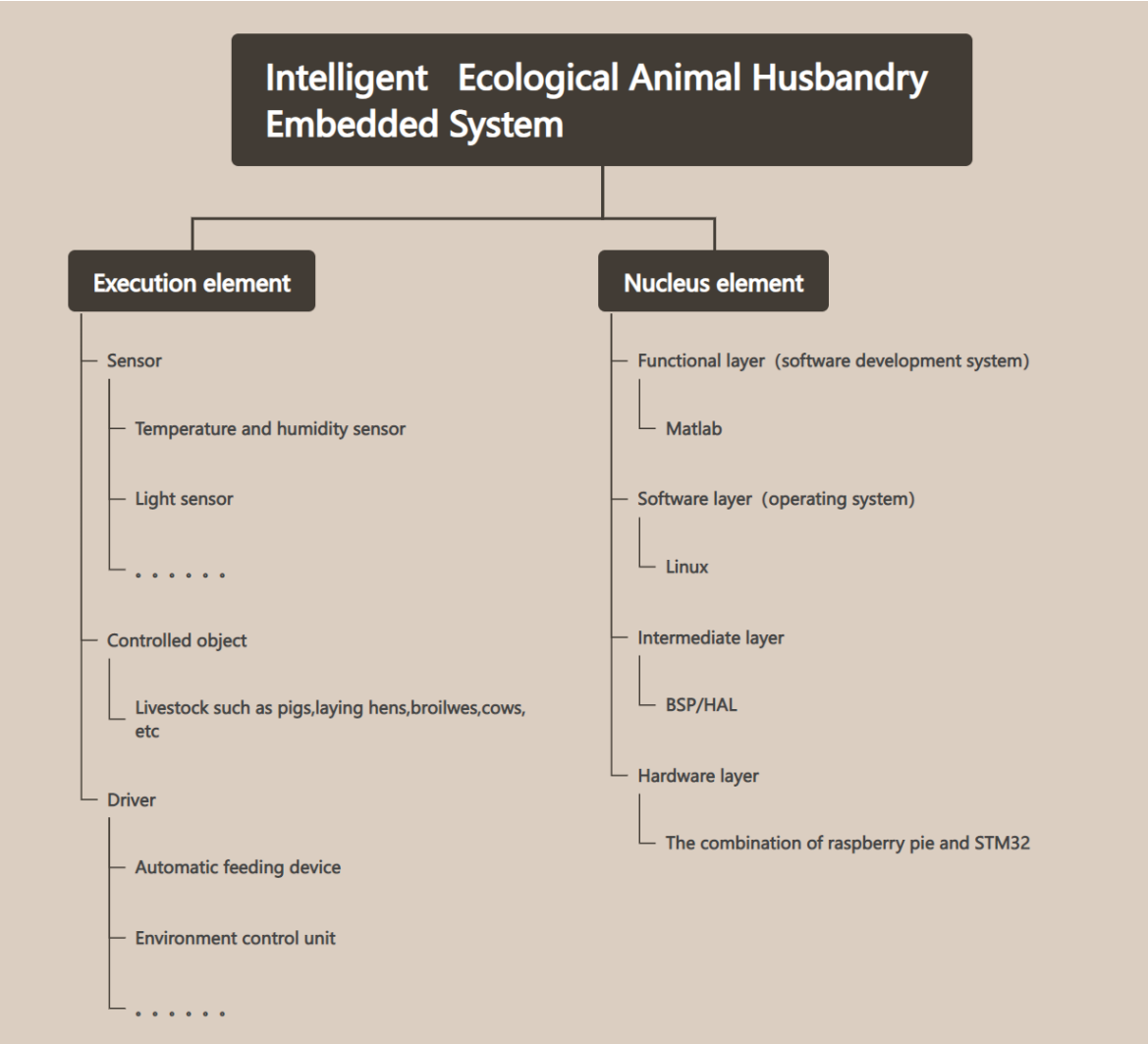

Figure 1: System flowchart

As illustrated in Figure 1, a comprehensive embedded system is composed of an execution unit and a core unit. The execution unit is further divided into sensors, controlled objects, and actuators. In the context of smart ecological livestock farming, the system should incorporate a suite of sensors, including but not limited to temperature and humidity sensors (e.g., DHT11), light sensors (e.g., BH1750), pulse sensors, and carbon dioxide/toxic substance sensors. These sensors are essential for comprehensive monitoring of the animals' living environment, enabling prompt intervention in response to anomalous conditions [10]. The controlled objects encompass livestock such as pigs, laying hens, broilers, and dairy cows. Actuators include wearable devices, automated feeding systems, environmental control equipment (ventilation, cooling, heating, etc.), and waste management systems. The specific selection of sensors and actuators should be tailored to the specific controlled objects and the practical requirements of the application.

Furthermore, the core unit is divided into a functional layer, a software layer, a middleware layer, and a hardware layer. The functional layer employs Matlab as the application software development platform, leveraging its robust algorithm development and data processing capabilities to facilitate rapid prototyping and hardware integration. The software layer operates on the Linux system, which

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ensures efficient system operation and scalability due to its open-source nature, flexibility, stability, and multitasking support. This combination effectively addresses the real-time requirements of complex environmental monitoring and automated control in agricultural farming, as well as simplifying development and maintenance.

The intermediate layers utilize the Board Support Package (BSP) and Hardware Abstraction Layer (HAL), corresponding to the selected hardware in the hardware layer, where the hardware selection is of paramount importance. For smart ecological livestock farming, a combination of Raspberry Pi and STM32 can be employed. The Raspberry Pi, equipped with an ARM Cortex-A series processor (e.g., Cortex-A72/A76), offers substantial computational capabilities. Furthermore, the Raspberry Pi provides standard interfaces such as HDMI, USB, Ethernet, CSI (camera interface), and DSI (display interface), facilitating the connection of peripherals and network connectivity. This makes it suitable for applications requiring high-performance computing, graphical interfaces, or complex operating systems, such as smart gateways, video surveillance, and user interaction devices, while also enabling connection to user-end platforms. The STM32, on the other hand, excels in real-time performance, making it ideal for control tasks that demand rapid response. Its design adheres to industrial-grade standards, offering high anti-interference capabilities, stability, and cost-effectiveness. It is well-suited for applications requiring low power consumption, real-time operation, and high reliability, such as sensor nodes, industrial control systems, and embedded systems, and is appropriate for large-scale production. Together, the integration of Raspberry Pi and STM32 allows for more efficient system design [10-11].

This design effectively meets the core requirements of smart ecological livestock farming by implementing environmental control equipment for comprehensive monitoring and management of the livestock farm environment, animal health, and resource utilization, thereby significantly enhancing the production efficiency and management standards of the livestock industry.

The automated feeding system dynamically adjusts the allocation of feed and water resources, preventing resource waste and environmental pollution caused by overfeeding. Simultaneously, air quality sensors detect the emission of harmful gases and promote their treatment to achieve resource recycling, further minimizing environmental impact. Furthermore, the system optimizes energy consumption through the use of low-power embedded devices, supporting the application of renewable energy while reducing the carbon footprint.

This design not only enhances ecological sustainability and resource efficiency but also improves production effectiveness, offering an innovative approach to the green transformation of the livestock industry.

4.2. Fault tolerant design

In order to ensure that the system is put into actual production and use, as far as possible to reduce the impact of sensor failure, power interruption or network connection on the system operation, the system fault-tolerant design is added in the design.

The system configures multiple key sensors to prevent sensor failure. When the main sensor fails, the system will enable the standby sensor on its own. At the same time, the system is configured with STM32 to regularly calibrate the sensor. When a fault is detected, STM32 sends an alarm message through Raspberry Pi to remind the staff to repair in time.

For the power supply interruption problem, the system will immediately save the key data to the non-volatile memory when the power supply abnormality is detected by real-time monitoring. After the power supply returns to normal, the system will automatically restart and restore the pre-interrupt state.

In addition, Raspberry Pi maintains regular communication with STM32 to detect network status. When the network connection problem is detected, such as network interruption, the system

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automatically reconnects the network, while STM32 temporarily stores the data locally, and restores the normal transmission of data after the network returns to normal.

4.3. Feasibility analysis

The combination of raspberry pie and STM32 is widely used in various fields of real life. Such as the farmland monitoring system based on Raspberry Pi 4B and STM32L4, which analyzes environmental data in real time and automatically triggers precise pest control [12], the intelligent shopping guide robot based on Raspberry Pi 4B and STM32F4 realizes product selection and intelligent path guidance through WeChat applet or touch screen interaction [13]. Therefore, the embedded system proposed in this paper has certain feasibility and realizability. With large-scale animal husbandry farms as the application environment, the embedded system combined with raspberry pie and STM32 can perfectly meet its needs in the production process and has high feasibility.

First of all, raspberry pie, with its powerful data processing capabilities and rich software ecology, can efficiently process massive environmental data (including temperature, humidity, light, harmful gases, etc.) collected by sensors from all over the farm, and store, analyze and transmit the data. STM32 focuses on real-time control, which can accurately control various actuators such as feeding machine, manure cleaning equipment and ventilation system to realize automatic operation. The two work together to meet the comprehensive needs of large-scale data processing and real-time precise control of large-scale livestock farms.

Secondly, both raspberry pie and STM32 are open source hardware, with rich expansion interfaces and modules, which can flexibly expand functions according to the actual needs of the farm, such as connecting more sensors and controlling more devices. At the same time, both of them are relatively low cost and have low power consumption characteristics, which are suitable for large-scale deployment of large-scale livestock farms with low cost investment.

In addition, the embedded system of raspberry pie combined with STM32 can build a sensor network covering the whole farm, monitor the environmental parameters of the farm in real time, provide a comfortable growth environment for livestock and poultry, and improve the breeding efficiency. According to different types of livestock and poultry, growth stages and individual differences, the system can achieve precise feeding, optimize feed utilization and reduce breeding costs. The system 's image recognition, sound analysis and other technologies can monitor the health status of livestock and poultry in real time and prevent disease outbreaks. Automated manure removal, drinking water, grouping and other operations can directly reduce labor costs, improve production efficiency, and thus enhance the overall efficiency of large animal husbandry farms [12].

4.4. System in extreme environments

Animal husbandry environment usually has extreme conditions such as high humidity, dust and temperature fluctuation, which poses a serious challenge to the stability and reliability of electronic equipment. High humidity may lead to circuit board corrosion, short circuit and other problems, affecting the normal operation of the system. The dust accumulation may lead to poor heat dissipation, and even block the interface, affecting the performance of the equipment. Extreme temperature can lead to performance degradation or even damage of electronic components.

The modular design of raspberry pie and STM32 can separate the core control module from sensors and actuators, which is convenient for protection. Industrial-grade raspberry pie and STM32 can adapt to the temperature fluctuation of animal husbandry environment due to their wide working temperature range. The sealed, dust-proof and moisture-proof protective shell designed for raspberry pie and STM32 is equipped with a heat dissipation fan or heat sink to ensure the stable operation of the equipment in harsh environments such as high temperature. In addition, it is also necessary to

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regularly clean the dust of the system and equipment, check the connection line, replace the aging components in time, and prolong the service life of the equipment.

The extreme environment of animal husbandry has certain challenges to the system, but the stability and reliability of the system can be effectively improved through reasonable protective measures, device selection and system optimization, so that it can play an important role in the field of animal husbandry [14].

4.5. Deficiency

The system may face some hardware and network bottlenecks in the actual deployment, which need to be planned and solved in the application.

In terms of hardware, raspberry pie has certain limitations in computing power and storage space, and its computing power may be difficult to cope with a large number of sensor data processing and complex algorithm operation (such as image recognition and machine learning). At the same time, external storage devices or cloud storage solutions are needed to meet the storage requirements of a large amount of historical data (such as environmental data and video surveillance). STM32 is limited by memory resources and limited memory. It needs to optimize the code when dealing with complex control logic or storing large amounts of data, which increases the difficulty of system maintenance.

For the network, the large livestock farm area is vast, the deployment cost of wired network is high, and the coverage and signal strength of wireless network may not meet the demand. When a large amount of data (such as video stream, sensor data) needs to be transmitted, network problems may lead to data transmission delay or loss. At the same time, the environment of livestock farms is complex, and there may be problems such as electromagnetic interference and signal occlusion, which further affect the stability of the network.

5. Conclusion

The development of intelligent ecological livestock farming offers an inevitable chance for the modernization of the livestock industry. Building upon the current state of research, this paper focuses on in-depth exploration and innovation in embedded systems to promote technological advancements and application expansion in this field.

However, there are some limitations in the research process of this paper, which need to be further improved and improved in the future work. The research of this paper is mainly based on theoretical analysis, lacking of practical case verification. Additionally, the absence of experimental data limits the ability to fully demonstrate the real-world application of embedded systems in intelligent ecological animal husbandry. Future research should focus on developing dynamic body temperature detection technologies to enable accurate real-time monitoring under various conditions.

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