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Intelligent agricultural mechanization: A new era engine for agricultural development

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Abstract. In recent years, the rapid advancement of technology and the increasing demand for efficient agricultural practices have propelled significant progress in the field of intelligent agricultural mechanization. This paper aims to comprehensively explore this important topic by analyzing the key role of intelligent agricultural mechanization in modern agriculture, examining its technological applications, and identifying prevailing challenges. Intelligent agricultural mechanization involves the integration of cutting-edge technologies such as artificial intelligence, machine learning, and the Internet of Things (IoT) into agricultural machinery and processes, revolutionizing traditional farming methods. Through an in-depth study of relevant literature, it elucidates how intelligent agricultural mechanization can significantly enhance agricultural production efficiency by minimizing resource waste, reducing labor costs, and increasing crop yields. Furthermore, the paper explores the broader implications of these advancements for sustainable development. The research results presented herein seek to provide robust theoretical support and practical guidance for advancing agricultural modernization. In this paper, future development trends are also discussed, including the potential for further innovations and the role of policy and regulatory frameworks in facilitating the adoption of intelligent agricultural mechanization.

Keywords: Artificial Intelligence, Modern Agriculture, Intelligent Agricultural Mechanization, Sustainable Development.

1. Introduction

Agriculture, the foundation of human society, has always sought to innovate and adapt in order to fulfil the demands of sustainable development as well as the rising demand for food. The agricultural sector is adopting new technologies due to pressures from population growth, climate change, and the need for sustainable resource management. Modern agricultural modernization is primarily driven by intelligent agricultural mechanization, which has evolved as a result of science and technology developing at a rapid pace. The incorporation of cutting-edge technology like artificial intelligence, machine learning, and the Internet of Things into agricultural machinery and procedures is known as intelligent agricultural mechanization. The paper aims to conduct a detailed investigation into the vital role that intelligent agricultural mechanization plays in modern agriculture. Therefore, it looks at its technical applications and current issues in an effort to provide strong theoretical backing and useful advice for furthering agricultural modernization. The research demonstrates the potential of intelligent agricultural mechanization to enhance production efficiency, optimize resource allocation, and facilitate sustainable development. This is achieved through a comprehensive examination of pertinent data and literature. Furthermore, the technical challenges associated with intelligent agricultural mechanization are examined, and strategic recommendations for surmounting these challenges are presented. In conclusion, the research offers perspectives and direction for surmounting technological obstacles linked to intelligent agricultural automation.

2. Key Technologies for Intelligent Agricultural Mechanization

2.1. Precision Agriculture Technology

Precision agriculture technologies include various advanced techniques such as Global Positioning System (GPS), Geographic Information System (GIS), and Remote Sensing (RS) [1]. The integration of these technologies enables precise mapping of farmland, monitoring of soil nutrients and moisture, and provides a scientific basis for precision seeding, fertilization, and irrigation. In particular, the use of GPS enables the accurate positioning and measurement of farmland, thus allowing farmers to determine the precise location and area of each plot. RS technology gathers information over extensive areas of farmland, such as soil conditions and crop growth, thereby enabling farmers to gain a comprehensive understanding of the overall status of their fields in real time. GIS integrates and analyzes these agricultural data sets to provide robust support for agricultural production decisions, thereby enabling farmers to manage and optimize production processes in a scientifically informed manner based on actual conditions. The implementation of these technologies not only enhances agricultural production efficiency but also minimizes resource wastage and fosters sustainable agricultural development.

2.2. Agricultural Robot Technology

Among other difficult activities, agricultural robotics technology can do a variety of duties like sowing, weeding, fertilizing, controlling pests, and harvesting. These robots have many benefits, including excellent efficiency, precision, and round-the-clock functionality. For example, harvesting robots can recognize and select ripe fruits with accuracy [1]. Harvesting crops can be done in two ways: non-selective harvesting and selective harvesting. In non-selective harvesting, robots pick and sort plants and fruits from row crops like corn, soybeans, and cotton. Regarding this, the robot’s eyesight mainly focuses on differentiating between soil and crops, directing its movements accordingly. Besides, selective harvesting entails removing ripe fruits without compromising the growth of the plant. More work than non-selective harvesting, this needs the robot's vision to distinguish between fruits and plant stems and leaves. Selective harvesting includes the picking of common crops grown in greenhouses, such as tomatoes and cucumbers. While seeding robots achieve exact sowing to improve planting efficiency and quality, weeding robots are made to precisely identify and eradicate weeds. By cutting labor costs and minimizing chemical usage, these robotic solutions not only improve agricultural operations but also support sustainable farming practices [1].

2.3. Intelligent Sensor Technology

Intelligent sensor technology plays a pivotal role in modern agriculture by continuously monitoring crucial environmental parameters in farmland, including temperature, humidity, and light intensity, to provide precise data for informed agricultural decision-making. These sensors can precisely measure soil moisture content, temperature, pH levels, as well as air temperature, humidity, and light intensity, which provides farmers with real-time and accurate agricultural production data. The implementation of real-time monitoring systems for crop growth and pest conditions enables farmers to make timely adjustments to irrigation, fertilization, and pesticide treatments, which can result in reduced resource wastage and mitigation of environmental impacts, as well as improved crop yields and quality. The adoption of these sophisticated technologies not only enhances the efficiency and sustainability of agricultural production, but also facilitates the modernization of agricultural practices. For example, Maharlooei et al. employed image processing techniques to monitor the status and enumerate the number of aphids on soybean leaves [2]. The acquired images are processed to identify and count the number of

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mites, a method that is low-cost and experimentally proven to be extremely accurate under well-lit conditions. The disadvantage of this method is that the results vary in low light conditions. Recognition methods based on spectral features of the target are more stable and accurate [3]. In addition, Michael Halstead et al. proposed a robotic vision system using a Parallel-RFCNN structure to accurately estimate the ripeness of bell peppers [4]. The model can accurately estimate the maturity, with an average accuracy of 82.1% [1][5].

2.4. Automatic Control Technology

Modern agriculture depends much on automatic control technology since it allows autonomous driving, automatic operations, and remote control of agricultural equipment, so improving efficiency, quality, and safety. This technique achieves exact monitoring and automated control all through the agricultural production process by use of sophisticated sensors, computer systems, and mechanical equipment. From soil cultivation, seed sowing, and irrigation to pest control, crop harvesting, and storage, agricultural automation technology spans the entire production chain. By continuously collecting real-time environmental data from fields and employing intelligent analysis, this system automatically adjusts the operational status of agricultural equipment to ensure crops are maintained in optimal growing conditions [1]. This advancement not only greatly improves agricultural productivity, reduces labor intensity, and enhances crop yield and quality but also strengthens the competitiveness of the agricultural industry. The widespread adoption of automatic control technology not only drives agricultural modernization but also provides vital support for sustainable agricultural development.

3. Applications of Intelligent Agricultural Mechanization

3.1. Planting

The deployment of intelligent agricultural mechanization technologies in the planting stage is progressively common in modern agriculture. Intelligent seeders, fertilizers, and harvesters have especially improved the accuracy and effectiveness of planting activities [6]. Using cutting-edge positioning and sensing technology, intelligent seeders may independently precisely complete planting chores, therefore removing mistakes and repeated manual labor. Precision control mechanisms included into fertilizers allow them to rapidly change their dosage depending on soil quality and plant nutrient requirements, therefore improving the quality and production of the crops. Equipped with intelligent harvesting heads and image recognition algorithms, harvesters autonomously identify and harvest mature crops, therefore saving labor costs and time waste and enhancing harvesting efficiency and quality of agricultural output.

3.2. Animal Husbandry

Intelligent agricultural technology is widely used in animal husbandry, particularly in automated feeding systems, environmental control technologies, and health monitoring systems. Automated feeding systems employ preset feeding protocols and intelligent sensors to monitor animals’ dietary intake and health status in real-time, ensuring precise feed management. Environmental control technologies play a crucial role by finely regulating parameters such as air quality, temperature, and humidity, creating optimal conditions for animal growth. This not only reduces the risk of disease but also enhances overall farming efficiency and production stability. Meanwhile, health monitoring systems continuously track animals' health metrics and behavioral patterns, facilitating early disease detection and prevention. Such integrated systems elevate farming management standards and contribute to improved animal welfare outcomes [7].

3.3. Facility Agriculture

Intelligent irrigation, ventilation, and lighting control technologies have greatly improved crop growth conditions and production efficiency in facility agriculture, particularly in greenhouse cultivation systems. Intelligent irrigation systems accurately regulate the amount and timing of watering by

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considering soil moisture levels and crop water needs. This helps prevent water waste and the potential harm of soil salinization. They also enhance crop water use efficiency and drought resistance. Ventilation systems automatically regulate airflow and air quality inside and outside the greenhouse, maintaining optimal temperature and humidity conditions. This measure effectively mitigates the emergence of fungal infections and heat stress, hence assuring optimal and robust crop growth. Lighting control systems precisely regulate light intensity and photoperiod based on crop growth phases and weather conditions, enhancing photosynthesis efficiency and accelerating crop growth rates. This integration facilitates the preservation of energy and resources while also promoting sustainable development [8].

4. Advantages and Challenges of Intelligent Agricultural Mechanization.

4.1. Advantages Provided

Intelligent agricultural mechanization technologies have brought multiple advantages to modern agriculture, primarily encompassing the following aspects [9]:

4.1.1. Enhanced Production Efficiency. Intelligent agricultural mechanisation greatly reduces the amount of labour required by automating and accurately carrying out tasks, resulting in shorter operational cycles and higher yield per unit area. This method not only enhances agricultural productivity but also promotes industrialization, expansion, and specialization within the agricultural sector. By advocating for advanced agricultural technologies, we may achieve synchronized progress throughout all stages of agricultural production, thereby boosting total productivity and economic gains.

4.1.2. Precise utilization of resources. Intelligent agricultural technologies enable precise regulation of fertilization and irrigation according to crop growth requirements. Leveraging advanced sensors and data analytics, precise monitoring and management of soil nutrients, water, and light resources can be achieved, reducing resource wastage and environmental pollution. Through precise fertilization and irrigation, crop growth efficiency and quality are improved, while ensuring the sustainability of the ecological environment.

4.1.3. Improved Crop Quality. The standardization of operations facilitated by intelligent agricultural technologies ensures consistency and quality stability throughout the agricultural production process. By precisely controlling production environments and operations, the influence of human factors on crop quality is minimized, enhancing product market competitiveness and consumer trust. Standardized operations also assist agricultural products in meeting national and international quality standards, thereby expanding market opportunities.

4.1.4. Strengthened Agricultural Resilience. Intelligent agricultural technologies not only enhance production and resource utilization efficiencies but also bolster agricultural systems' resilience against natural disasters, pests, and diseases. Through real-time monitoring and early warning systems, farmers can promptly access information on crop growth status and environmental changes, enabling effective management and response measures to reduce disaster losses and economic risks. Strengthening this capability helps safeguard the stability and sustainable development of agricultural production.

4.2. Challenges Faced

The promotion and application of intelligent agricultural mechanization technologies face various challenges, primarily encompassing the following aspects [10]:

4.2.1. High Technological Costs. Intelligent agricultural mechanization requires substantial investment in advanced equipment and high levels of technological research and application. The technological costs involved are significantly higher than traditional agricultural methods, limiting the widespread

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adoption and dissemination of intelligent agricultural technologies among farmers. While advancements and economies of scale may eventually reduce costs, current financial investments remain a significant limiting factor.

4.2.2. Technological Adaptability. Diverse agricultural production conditions, climatic environments, and crop varieties across different regions pose challenges to the universality and adaptability of intelligent agricultural technologies. Some advanced agricultural technologies may not be applicable or effective in specific geographic, socioeconomic, or cultural contexts, necessitating targeted technological improvements and adaptability adjustments. Moreover, acceptance and utilization of new technologies by farmers are influenced by traditional practices and cultural factors, further complicating the widespread adoption of technology across different regions.

4.2.3. Data Security and Privacy Protection. Intelligent agricultural mechanization relies on big data analytics and internet technologies, involving the collection, transmission, and storage of large amounts of agricultural production and management data. However, the security and privacy protection of this data face potential risks and challenges. Issues such as data breaches, cyber-attacks, and unauthorized data access can lead to economic losses and privacy concerns for agricultural producers. Thus, strengthening data security management and implementing technical protection measures are essential to ensure the security and lawful use of data.

4.2.4. Shortage of Skilled Professionals. The promotion and application of intelligent agricultural technologies require professionals who possess both agricultural knowledge and expertise in information technology, a combination that is relatively scarce in the current job market. Integrating agricultural expertise with a deep understanding of information technology demands comprehensive skills and specialized knowledge from professionals. Therefore, enhancing interdisciplinary education in agriculture and information technology is crucial for cultivating more skilled professionals capable of supporting the long-term development and application of intelligent agricultural technologies.

5. Future Trends in Intelligent Agricultural Mechanization

5.1. Integrated and Innovative Technologies

In the future, intelligent agricultural mechanization will prioritize the integration and innovation of modern technologies like as artificial intelligence, big data, and IoT. Agricultural machinery will enhance operational management and optimize resource usage through the implementation of data-driven intelligent decision systems and adaptive control technology. Artificial intelligence algorithms will improve the accuracy and predictive capacities in agricultural output, while big data analytics will offer scientific foundations for making decisions in agriculture. The extensive implementation of IoT would facilitate instantaneous communication and cooperative functioning among gadgets, hence propelling the progress of sophisticated mechanization towards intelligence, automation, and intelligent services.Intelligent and Miniaturized Equipment.Upcoming advanced agricultural gear will increasingly prioritize intelligence, flexibility, and adaptability to cater to small-scale farmlands. Advancements in miniaturized equipment would provide more precise control and functioning in agricultural production, catering to the growth needs of various crops and specific geographical situations. The utilization of sophisticated sensors and machine vision technologies will enable equipment to continuously monitor and promptly adapt to crop growth circumstances and environmental fluctuations. This would facilitate individualized agricultural production management.

5.2. Innovative Service Models

In the future, there will be an increase in the number of agricultural mechanization service firms that offer comprehensive intelligent agriculture solutions. These firms will combine services such as technological development, equipment leasing, technical training, and support to provide tailored

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agricultural production solutions to farmers. The implementation of new service models will facilitate the wider use and integration of intelligent agricultural gear, resulting in reduced expenses for farmers when acquiring technology and increased receptiveness and eagerness to utilize new technologies.

6. Conclusion

Intelligent mechanization in modern agriculture is an inevitable trend, crucial not only for enhancing agricultural productivity and quality but also for providing effective solutions to global challenges such as food security and promoting sustainable agricultural development. Despite facing challenges such as high technology costs, poor technological adaptability, data security issues, and talent shortages during its development, these challenges can be overcome gradually. Firstly, technological innovation is a significant factor in the advancement of intelligent mechanization. The implementation of artificial intelligence, big data analysis, the Internet of Things, machine vision, and other state-of-the-art technologies will serve to augment the intelligence and automation levels of agricultural production, thereby facilitating the precise management and optimization of the agricultural production process. Secondly, policy support serves as a crucial enabling factor for the accelerated advancement of intelligent mechanization. It is imperative that the government formulates policy measures to support the modernization and intelligent transformation of agriculture. Such measures should include financial subsidies, technology promotion, and market access policies, with the objective of reducing the cost of technology, promoting the application of technology, and popularizing intelligent agricultural machinery. Ultimately, the long-term viability of intelligent mechanization hinges on the cultivation of a skilled workforce. It is imperative to reinforce the training of multidisciplinary professionals in the domains of agricultural engineering, information technology, and data science to facilitate the advancement of intelligent agricultural machinery.

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