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Transformation of Agriculture through Artificial Intelligence: A Comprehensive Review

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

Artificial Intelligence (AI) is a transformative sector of computer science field that focuses on generating intelligent system and machines capable of performing tasks that typically require human intelligence. These tasks include learning, reasoning, problem-solving, perception, and language understanding. With advance development in AI technologies, used into diverse fields such as healthcare, education, agriculture, business, and autonomous systems. AI employs techniques such as machine learning, neural networks, and natural language processing to analyze and interpret vast amounts of data, enabling predictive analytics, decision-making, and automation. The use of AI into various industries is revolutionizing workflows, enhancing productivity, and creating innovative solutions to complex challenges. However, the field also presents ethical considerations and challenges, such as data privacy, data security, bias, and the impact on employment.

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1. INTRODUCTION

Artificial Intelligence (AI) is a branch of computer science focused on developing intelligent machines capable of performing tasks that typically require human intelligence. AI research is highly specialized and technical, and its influence spans across various domains, including business, technology, and education. In the coming years, AI is poised to revolutionize education and other critical fields. This paper provides the information of significance and impact of Artificial Intelligence in the field of agricultural information research. Due to adoption of AI technologies in agricultural sector it transform the agricultural industry, addressing numerous challenges and threats. AI applications used in agriculture provide valuable solutions, such as automation in processes, improving decision-making and enhancing resource efficiency used in agricultural. This paper focuses on the diverse applications of AI in agriculture, highlighting its potential to optimize agricultural practices and ensure sustainable development in this different sector.

2. DEFINITION OF ARTIFICIAL INTELLIGENCE (AI)

The definition of Artificial Intelligence (AI) has been evolved over time due to its rapid growth and development. Most of the definitions can be categorized into four perspectives: AI as a system that thinks like a human, acts like a human, thinks rationally, or acts rationally. (Kakani V, et al., 2020). In the 1950s, Alan Turing introduced the concept of AI where he proposed the famous Turing Test to answer the question, “Can a machine think?” To pass the Turing Test, a machine must demonstrate four key capabilities: natural language processing, knowledge representation, automated reasoning, and machine learning. While Turing's definition remains influential, it faced criticism for failing to differentiate knowledge from intellect, akin to distinguishing software from hardware in the context of computing.

Another definition described AI as “a program that, in an arbitrary world, will perform no worse than a human.” This implies that AI operates as a system of programs with defined inputs, outputs, and an environment in which it functions.

2.1 Types of Artificial Intelligence (AI)

Arend Hintze**,** (G. Mahibha & P. Balasubramanian) categorizes AI into four distinct types. These categories range from the AI frameworks currently in use to those with the potential for consciousness in the future:

1. **Reactive Machines: (G. Mahibha & P. Balasubramanian)** Reactive machines AI systems operate based on current input and due to lack of storage it is unable to draw insight from past into present. Deep Blue, the IBM chess program that defeated Garry Kasparov in the 1990s, serves as a model IBM's Deep Blue, a chess-playing computer that analyses moves but doesn't "learn" or improve with experience. So every time it analyse potential moves, both its own and those of opposition and select the most important move.
2. **Limited Memory: (G. Mahibha & P. Balasubramanian)** Limited memory systems can use past experiences to inform current decisions. They store some data temporarily but don't form memories or learn long-term. Autonomous vehicles like self-driving cars which use sensor data to navigate and respond to immediate road conditions.
3. **Theory of Mind: (G. Mahibha & P. Balasubramanian)** Theory of mind type refers to AI that can understand emotions, beliefs, and thoughts of others. It remains in developmental stages and aims to build systems that interact socially like humans. Advanced robotics designed to engage in complex human interactions.
4. **Self-Aware AI: (G. Mahibha & P. Balasubramanian)** Self-Aware AI are advanced and hypothetical form of AI, it possesses consciousness and self-awareness. Such systems would be able to understand their own existence, desires, and emotions. Currently, this remains a theoretical concept and is not yet realized.

2.2 Applications of Artificial Intelligence in Agriculture

Applications of AI span a wide range of fields, including:

- **Intelligent information retrieval** from databases.

- **Expert consulting systems** for specialized problem-solving.
- **Theorem proving** in mathematics.
- **Robotics** for automated physical tasks.
- **Automatic programming and scheduling** for resource optimization**.** (Shekhar Y, Dagur E, Mishra S, Tom RJ, Veeramanikandan M, Sankaranarayanan S. Intelligent IoT based automated irrigation system, 2017)
- **Soil Management:**

Soil is one of the most crucial factors for successful agriculture. As the primary source of nutrients, soil stores essential elements like water, nitrogen, phosphorus, potassium, and proteins that are vital for proper crop growth and development. Soil condition can be enhanced through the addition of compost and manure, which improve soil aggregation. Proper soil management can minimize negative factors such as soil-borne pathogens and pollutants. Additionally, AI can be used to create detailed soil maps, revealing soil-landscape relationships and the various layers and proportions of soil underground.

- **Perception problems:** Such as image and speech recognition.

Artificial Intelligence (AI) is transforming the agricultural sector by improving efficiency and productivity in various ways:

- **Resource Management:** AI helps manage water resources effectively.
- **Weed Control and Crop Enhancement:** (Banerjee, et al., 2019) AI-powered systems assist in weed management, improving crop growth, and detecting diseases and pests. (Stigliani, et al., 1993). Artificial intelligence weed detection systems have been tested in laboratories to calculate the precise amount of spray to be used and to spray on the target location accurately, which also lower costs and the risk of damaging crops
- **Fertilizer and Nutrient Application:** Fertilizer distribution and nutrient provisioning are optimized through AI algorithms.
- **Drone Applications:** Drones capture and analyse images of fields, identify crop damage, and monitor overall health. They are also used for targeted application of herbicides, pesticides, and fertilizers.
- **Agri-bots:** AI-powered robots, or Agri-bots, act as modern combine harvesters, increasing yield and operating faster than human labor.AI technology is increasingly adopted in regions like India, where its integration into agriculture has not only improved efficiency but also attracted younger generations to farming.
- **AI in Crop Health Monitoring (Adapa Shalini Pujitha, Beera Anusha, and Ajay Kumar Prusty, 2023)**

AI systems monitor crop health using advanced tools and techniques:

- **Independent Rovers:** These robots move through fields, capturing data with cameras. The images are analysed using algorithms like MATLAB to detect diseases and nutrient deficiencies.
- **Drone Technology:** Drones with cameras help identify pest infestations, water deficiencies, and crop health issues. They apply fertilizers and pesticides precisely where needed, ensuring resource efficiency.
- **Wireless Sensors:** These sensors gather vital ecological data, such as soil moisture, temperature, and humidity, enabling real-time crop management.
- **Weather Forecasting:** Weather forecasting plays a crucial role in agriculture, and AI enhances its accuracy.

3. CHALLENGES OF PRACTICAL APPLICATION OF AI-BASED TECHNIQUES IN AGRICULTURE

- **Uneven Future Distribution of Mechanization**

The adoption of agricultural robotics is projected to grow, with annual increases of 9% in the U.S., 12% in Asia-Australia, and 8% in Europe between 2011 and 2013. By 2030, robot penetration is estimated to reach 15%, and 75% by 2045 (G. Mahibha & P. Balasubramanian, 2023).

However, this growth may not be evenly distributed due to:

- **Resource Disparity**: Regions with limited access to technology may struggle to adopt AI-based systems.

- **Infrastructure Challenges**: Remote or rural areas often lack the necessary internet access and technical expertise to implement AI.
- **Natural Constraints**: AI adoption may not necessarily increase food production beyond the physical limitations of land and resources. (G. Mahibha and P. Balasubramanian, 2023). These disparities highlight a slower and uneven adoption of AI in agriculture, potentially leaving underdeveloped areas behind. Discrepancies between Controlled Experiments and Real-world Implementation.

AI systems often perform well in controlled environments but face challenges in practical applications due to:

- **Variability in Conditions:** Real-world factors, such as lighting changes, complex backgrounds, and varied camera angles, affect image-based AI performance.
- **Heterogeneous Crops:** Physical differences in crops caused by pests, soil quality, or other factors complicate data processing.
- **Data Limitations:** A more extensive and diverse dataset is required to enhance classification accuracy in agricultural applications Security and Privacy Concerns AI systems in agriculture, particularly IoT devices, face significant security challenges:
- **Physical Vulnerability:** IoT devices, often placed in open spaces, are exposed to attacks like tampering, theft, or destruction.
- **Data Transfer Risks:** (Davenport et al., 2020) Data can be intercepted during transfer from devices to gateways or cloud servers, leading to potential breaches.
- **Cloud Security Threats:** Cyberattacks, such as session hijacking, login abuse, and denial-of-service (DoS) attacks, can compromise cloud infrastructure.

Security Measures to mitigate these risks include:

- **Encryption:** Protecting data during storage and transmission.
- **Frequency Modification and Tag Destruction:** Enhancing the security of IoT tags.
- **Authentication Mechanisms:** Verifying user and device identities.
- **Data Flow Policies:** Implementing strict controls over data access and movement.

Addressing these challenges is essential to ensure the safe, efficient, and equitable adoption of AI technologies in agriculture.

4. CONCLUSIONS

The integration of Artificial Intelligence (AI) in agriculture is revolutionizing the sector by enhancing productivity, resource efficiency, and sustainability. AI technologies, such as machine learning, robotics, IoT, and neural networks, offer transformative solutions for various agricultural challenges, including crop health monitoring, weed control, weather forecasting, and resource management.

Despite its numerous advantages, the practical application of AI in agriculture faces challenges like uneven mechanization distribution, discrepancies between experimental and real-world conditions, and security and privacy concerns. Addressing these issues requires strategic efforts, including improving infrastructure in underdeveloped regions, advancing AI algorithms for diverse field conditions, and implementing robust security measures.

In conclusion, while AI presents unparalleled opportunities to transform agriculture, its successful deployment requires addressing technological, infrastructural, and socio-economic challenges. A balanced approach will ensure equitable adoption, promoting sustainable agricultural practices and food security globally.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that generative AI technologies such as Large Language Models, etc. have been used during the writing or editing of manuscripts. This explanation will include the name, version, model, and source of the generative AI technology and as well as all input prompts provided to the generative AI technology.

Details of the AI usage are given below:

1. Chatgpt-mini40

COMPETING INTERESTS

Author has declared that no competing interests exist.

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