SMART TECHNOLOGIES FOR TRANSFORMING NEXT-GENERATION AGRICULTURE

DEEP LEARNING, IOT AND BLOCKCHAIN

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Smart Technologies for Transforming Next-Generation Agriculture: Deep Learning, IoT, and Blockchain

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CONTENTS

FOREWORD

In an age of rapid technological progress, agriculture—the bedrock of human civilization—is undergoing a profound transformation. The fusion of deep learning, the Internet of Things (IoT), and blockchain technology is revolutionizing the sector, offering innovative solutions to challenges in security, sustainability, and resource management. Smart Technologies for Transforming Next-Generation Agriculture: Deep Learning, IoT, and Blockchain serves as a guiding light for researchers, practitioners, and policymakers striving for a more intelligent, data-driven, and resilient agricultural future.

The agricultural sector faces pressing challenges, including climate change, resource scarcity, and a rising global population. Addressing these issues requires a seamless blend of traditional farming expertise and cutting-edge technological advancements. Deep learning empowers predictive analytics for crop yield optimization, pest management, and weather forecasting. IoT devices facilitate real-time monitoring and automation, while blockchain ensures transparency, traceability, and trust throughout agricultural supply chains.

This book moves beyond theoretical exploration, offering practical applications, real-world case studies, and forward-thinking insights that are shaping the future of agriculture. It demonstrates how these technologies empower farmers, enhance productivity, and foster sustainable practices—bridging the gap between innovation and implementation.

As we step into a new era of agricultural transformation, this work serves as a comprehensive guide to leveraging smart technologies for the benefit of humanity. It stands as a testament to the limitless possibilities that lie ahead and a call for collaboration among technologists, farmers, and policymakers to build a sustainable future.

I applaud the authors and editors for their vision and dedication to advancing agricultural technology. This book will undoubtedly inspire its readers to think creatively and act decisively, paving the way for a smarter and more sustainable farming landscape.

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PREFACE

Agriculture is the backbone of human civilization, providing sustenance and economic stability to billions around the globe. However, as the world grapples with challenges like climate change, population growth, and diminishing resources, the need for innovative solutions to revolutionize agricultural practices has never been more urgent. The convergence of advanced technologies, including Deep Learning, the Internet of Things (IoT), and Blockchain, has opened new horizons for next-generation agriculture, transforming traditional methods into intelligent, sustainable, and efficient systems.

This book, "Smart Technologies for Transforming Next-Generation Agriculture: Deep Learning, IoT, and Blockchain, explores the transformative potential of these cutting-edge technologies in addressing the multifaceted challenges faced by the agricultural sector. It delves into the integration of artificial intelligence for predictive analytics, IoT devices for real-time monitoring, and blockchain for transparency and traceability in supply chains.

Each chapter provides insights into the latest advancements, practical implementations, and the socio-economic impact of these smart technologies. The contributions from leading researchers and practitioners highlight case studies, applications, and emerging trends that showcase the potential of smart agriculture in enhancing productivity, sustainability, and profitability.

This book is intended for a diverse audience, including researchers, academicians, industry professionals, policymakers, and students. It serves as a comprehensive resource for understanding the synergy between technology and agriculture, paving the way for a future where innovation meets sustainability.

We are thankful to all our authors for contributing their insights in the form of chapters, which will inspire readers to embrace and contribute to the transformative journey of agriculture through smart technologies, ensuring food security and environmental preservation for generations to come. We are also grateful to our professional editors, Tushti and Sakshi, for their editing and proofreading of the book.

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CHAPTER 1

Harvesting Innovation in Agriculture through IoT and Blockchain Technology

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Abstract: Innovative technologies like IoT and blockchain transform businesses and other agricultural work. Emerging technologies like artificial intelligence and big data have unlocked new possibilities for operational efficiency and achieved the highest level of productivity through informed decision-making. Using the Internet of Things technologies, sensors transmit real-time data regarding the environment's state, crops' growth, and animals' well-being. Consequently, the information they gain facilitates them in making better decisions, where resources can be utilized to their maximum and output raised without compromising waste. Blockchain technology provides a solution for building agricultural supply chains with integrity and transparency. In this chapter, we explore how integrating blockchain technology with IoT in agriculture can unlock unexplored proficiency, sustainability, and robustness. It utilizes case studies and examines innovative irrigation systems, crop monitoring, and animal management applications. This chapter will explore the various methods of data collection from Internet of Things sensors to analyze and gain insight for more accurate decision-making processes. By examining the data accumulated over several years, business management can develop goals that aim to improve production measures, such as efficiency and effectiveness. The analysis of various aspects of the agricultural industry and the application of blockchain technology demonstrates how it can improve processes by streamlining operations and making the industry more transparent. It examines the identification and effectiveness of data-driven decisions in crop management. The yield data analysis from production is the basis for continuing the growth of the agricultural industry.

Keywords: Agriculture innovation, Blockchain technology, Capital monitoring, Crops management, Internet of things, Smart farming.

INTRODUCTION

Innovative technologies like IoT and blockchain, which are relatively new, have been used to modernize the agriculture industry. As a result, a new era of agricultural transformation has emerged. This way of farming utilizes innovative

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breakthroughs, such as advanced accuracy, transparency, and efficiency, from the fields through processing plants to the end consumer. Therefore, farming techniques have been revolutionized for generations. The Internet of Things (IoT) enables sensors in fields, machinery, and livestock to provide us with real-time data on humidity, crop health, and livestock health. Through this provision of a coherent system, the farmer's decisions are informed, hence optimizing the available resources. Blockchain technology ensures that the integrity and traceability of agricultural goods from obtaining them from the farms to the consumer's table is preserved, thus cultivating trust and responsibility in the food supply chains. The agricultural revolution shall create more abilities that meet users' and the planet's needs by applying the combined forces of the Internet of Things (IoT) and Blockchain (BC) technologies. Through this, the future holds a highly informed, unambiguous, and fair agricultural sector. Scratching the paper-based agricultural bookkeeping approach, an old method of recording farm activities, is merely a child's game with this approach. The fact that this is the most dynamic stage of agricultural industry development almost deprives me of control. First, the Internet of Things (IoT) and the blockchain will play a crucial role in the current technological revolution. Undoubtedly, the past decade of technology has been a testament to its success, as it has turned all constraints to dust and touched every segment of society. Now, these two innovations will lay the foundation for a bright future in technology. Regardless of whether it's in engineering, health industries, computer science, or anything at all, their distinctive impressions pervade every sphere in which they are active [1].

Overview of IoT and Blockchain technology

The introduction of new technology, integrating IoT and blockchain, in the agricultural sector has resulted in the creation of various approaches to farming processes. Sensors, drones, and intelligent machines make age-old agriculture technologies contemporary by acquiring data instantaneously about soil moisture, temperature, crop health, and livestock. This data allowed them to drive more precise decisions and resources and significantly reduce the amount of waste and the negative environmental impact [2].

The Internet of Things (IoT) has always been the fastest-discussed and searched trend in the present era. The IoT foundation serves as the "connection" between various IT sector devices within the IoT vision. Furthermore, dimension one points us to intelligent communication and smart metering. Accepting this notion's vision would create room for the development of a significant agricultural subsidiary, which would imply change and additional possibilities for innovation and expansion. With contributions from IoT and resilient sensors that can accumulate large amounts of data, enabling the optimization of production processes, the prosperity of agriculture is advancing rapidly toward a greener and cleaner solution. Automated systems can create vast amounts of high-dimensional information to gain a complete understanding of our system. For instance, Uncrewed Aerial Vehicles (UAVs) can capture images that provide real-time information on crop growth. We can pinpoint particular components of the area that may require more attention. These devices can record enormous amounts of data, which, if comprehended, can result in various desirable outcomes. The data extracted from the Internet of Things typically consists of a substantial volume of information, necessitating the utilization of specific methods to be of any use [3].

As technologies continue to advance and people utilize them more, they have enormous potential to transform agriculture and positively impact farmers' lives worldwide. Smart devices and connectivity inculcation can allegedly be achieved in two ways concerning the Internet of Things in agriculture. For example, you can download weather information from the internet and have intelligent IoT devices implement it locally, update it, and automatically adjust the watering schedule. In this regard, robot technologies intended to observe crops and deliver information on the consumption of chemicals, such as pesticides or fertilizers, through the IoT network will operate autonomously. Eliminating the possibility of human error and providing data input with 100% accuracy is a fantastic result of the standard machine learning ability to teach algorithms how to process image data. One phrase can summaries all these: Boosting the product while consuming less water [4].

Blockchain technology is a genius solution for transparency, traceability, and security in the agricultural supply chain, as it helps maintain a record of every possible movement and transfer of farm products. These records are immutable, as illustrated in Fig. (**1**). This is demonstrated by the fact that customers can find the source of their food and track its quality. It is a distributed database shared among a network and uses encryption to ensure security. Blockchains are becoming increasingly popular. Its design does not allow any changes to be made to the data it stores, making it highly secure and auditable. The cryptocurrency known as Bitcoin, which was initially invented, has the potential to be utilised in a broad range of various businesses.

CHAPTER 2

Harvesting Innovation: Exploring Challenges, Risks, and Ethical Pathways in the Integration of Smart Technologies with Agriculture

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Abstract: Smart technology integration in agriculture offers a bright path forward for innovation, but it also comes with a lot of risks, problems, and ethical issues. The implementation of advanced technologies and inventions has increased agricultural productivity. Agricultural technical support is provided to farmers to assist with their farming activities, from raising crop yields to cutting back on pesticides, fertilizers, and water use, to enhancing farm workers' working conditions. It's critical to keep in mind that the new technologies are not related to agriculture. By providing sufficient food and other essential commodities and services in a manner that is both profitable and socially responsible, agriculture can ultimately enhance environmental quality, social responsibility, and the overall well-being of people. This is what is meant by a sustainable agricultural system. Depending on the viewpoint taken, the idea under examination has different implications for appropriate technology: at the farm level, at the level of the agri-food industry, or in relation to the larger local or worldwide economy. This chapter will examine the challenging landscape of applying new technologies to agriculture, examining issues such as data privacy, cybersecurity vulnerabilities, and the potential to worsen socioeconomic inequalities. It also examines the ethical implications of labor displacement and automation and emphasizes shared equity and negative impacts. By adopting ethical pathways and successfully navigating these challenges in the agriculture sector, we can fully utilize smart technology to enhance sustainability, production, and resilience.

Keywords: Harvesting, Innovation systems, Precision agriculture, Robotic farming, Smart technology, Sustainable development.

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INTRODUCTION

Agriculture is the oldest and the most significant business enterprise in the world. The need for jobs and food demand is rising rapidly due to the world's population growth. The traditional methods of farming are insufficient to meet current food requirements while also creating jobs for billions of people globally [1]. Research is ongoing these days on automated methods to meet these demands. Due to a lack of labor, tighter laws, rising global population, and dwindling farming population, farmers are compelled to look for new alternatives such as Artificial Intelligence (AI). The limitations of traditional methods provide an opportunity to the research community- to discover AI-powered systems that have demonstrated superior effectiveness in terms of precision and resilience when compared to other options [2]. Providing universal solutions is a challenging task due to the constantly changing nature of agriculture, as conditions vary widely. Utilizing AI methods to analyze specific details of each situation enables us to deliver customized solutions tailored to address particular challenges [3]. The term “digital agriculture” describes the application of cutting-edge technology that has revolutionized the agriculture industry by improving the intelligence and efficiency of farm operations. Automated techniques like Artificial Intelligence (AI) gather and analyse agricultural data that can help enhance productivity [4]. There are a lot of research papers and inventions that are focused on the use of AI in many different sectors. Domains like agriculture, healthcare, education, economics, government, and other areas have all benefited greatly from AI. Since agriculture is a complicated issue in its own right , this paper aims to highlight studies that employed AI approaches in agriculture. A vital component of the world economy is agriculture. Over the past 21 years, there has been a rise in demand for appropriate and safer farming practices. AI-powered solutions can improve crop quality and output while also creating a model for farming. This essay offers a comprehensive analysis of AI methods applied to agriculture. The application of AI in agriculture is shown in Fig. (**1**).

This chapter provides an overview of the complicated realm of smart agriculture, looking at the developments in technology, possible risks, and ethical decisions that need to be taken for them to be effectively incorporated. The integration of smart technology in agriculture presents a promising avenue to improve work conditions for farm workers. AI can raise crop yields while reducing the need for pesticides, fertilizers, and water. These benefits come with significant risks, challenges, and ethical concerns. This chapter will explore the complex landscape of applying advanced technologies to agriculture, focusing on issues such as data privacy, cybersecurity vulnerabilities. It will also examine the ethical implications of automation and ensure that the benefits of these technologies are shared equitably. While the vast majority of these emerging technologies originate outside the agricultural sector, they hold the potential to drive a more sustainable agricultural system—one that improves environmental quality, social responsibility, and overall well-being. The concept of sustainability in agriculture can be viewed from various perspectives, whether at the farm level, across the agri-food industry, or within the broader local or global economy. Smart agriculture sustainable development involves the use of advanced technologies and environmentally friendly methods to increase productivity while conserving natural resources for generations to come. Through the use of instruments such as precision farming, IoT sensors, artificial intelligence, and data analytics, smart agriculture ensures effective utilization of water, land, and energy, minimizing wastage and harm to the environment. This method not only enhances crop yields and farmer incomes but also improves biodiversity, fights climate change, and provides food security in an increasing global population. In the end, smart agriculture is a prime example of how innovation can propel sustainability in agriculture.

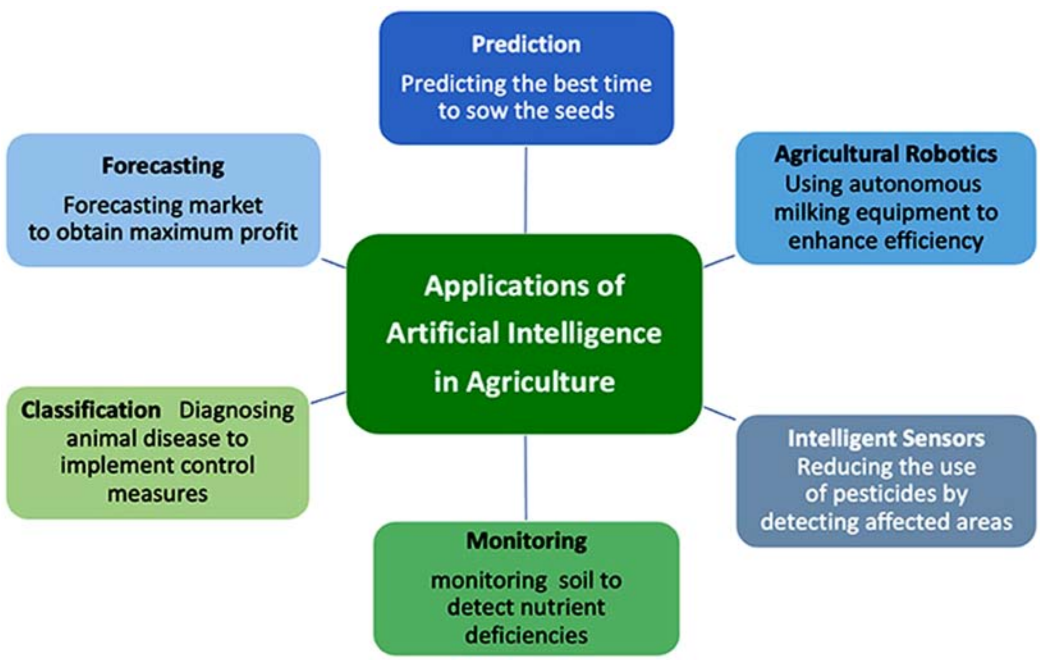

Fig. (1). Different AI applications in the field of agriculture.

In this chapter, our contributions are as follows. The technological innovation in the smart agriculture industry is covered in Section II. Section III discusses the challenges in integrating smart technologies with the agriculture industry; this makes up the majority of this chapter's discussion. It also covers technical

CHAPTER 3

Revolutionizing Crop Disease Detection with Computational Deep Learning-based Techniques

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Abstract: The early detection and classification of crop diseases is crucial in sustainable agriculture. Traditional inspection methods involve a lot of labor and are prone to errors. Therefore, the need for automated solutions for the detection of crop diseases has emerged. Deep learning techniques, especially Convolutional Neural Networks (CNNs), use image analysis to automate disease detection and classification. In this chapter, we analyze the performance of pre-trained deep learning models (DenseNet, MobileNet, EfficientNetB7) on a public benchmark encompassing annotated images of crops with diseases. The chapter discusses the role of transfer learning and fine-tuning of models to classify several diseases. The experimentation performed on the CCMT dataset is evaluated using accuracy, precision, recall, and F1 score metrics. Results indicated that MobileNet exhibited superior accuracy and balanced performance, making it a promising model for automated crop disease classification. However, addressing challenges in distinguishing visually similar diseases remains a priority for future research. The chapter discusses potential avenues for enhancing model performance, incorporating domain knowledge, improving data diversity, exploring advanced architectures, and ensuring model interpretability. Deep learning models show immense potential in revolutionizing crop disease detection, contributing to sustainable agricultural practices and global food security.

Keywords: CNN, Crop disease, Deep learning, Smart farming, Transfer learning.

INTRODUCTION

One of the critical challenges in modern agriculture is the early detection of crop diseases, with far-reaching implications for global food security and sustainable farming practices [1, 2]. Crop diseases can lead to yield losses and reduced crop quality, thereby threatening the farmers' livelihood. Traditionally, crop disease detection depended on expert manual inspection, which was time-intensive and vulnerable to inconsistencies [3]. In recent years, the emergence of deep learning

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techniques, particularly in computer vision, has paved the way for the automated detection and classification of crop disease. CNNs are robust architectures for extracting intricate visual features from plant images, enabling accurate identification of various disease symptoms [4, 5].

The chapter provides insightful information on using deep learning models for effectively diagnosing crop diseases as well as the challenges and drawbacks, such as biases in the dataset or the model's generalizability. The chapter also provides directions for future research. The chapter also presents a comprehensive approach that employs pre-trained deep-learning architectures for crop disease detection. For this purpose, we use the open-source CCMT plant dataset, which consists of a diverse range of crop images annotated with disease labels [6]. The transfer learning approach involves fine-tuning pre-trained deep-learning models for crop disease detection [7]. It leverages the knowledge learned by models trained on large-scale image datasets, such as ImageNet, and adapts it to our target domain with relatively few annotated examples. This approach enables efficient utilization of computational resources and accelerates the model training process, making it feasible to explore multiple architectures and experimental settings.

Improving agricultural productivity and sustainability could be significantly impacted by the effective use of deep learning models in crop disease detection [8, 9]. Farmers can reduce output losses and slow the spread of illnesses by applying appropriate treatments, including targeted pesticide application or crop management techniques, when crop diseases are reliably identified and diagnosed early. Additionally, deep learning-based automated disease detection systems can reduce the need for chemical pesticides. Furthermore, by guaranteeing the production of robust and healthy crops, incorporating these cutting-edge technologies into agricultural systems may help improve global food security [10 - 12].

Our practical approach is based on designing training procedures and evaluation metrics to ensure adequate performance assessment. The experimentation involves standard protocols for dataset partitioning, including train-validation-test splits.

The experimentation revealed promising performance across different deep-learning architectures. Specifically, DenseNet achieved an accuracy of 92% with an F1 score of 91.3%, while MobileNet demonstrated an accuracy of 93.4% with an F1 score of 92.8%. EfficientNetB7 exhibited slightly lower accuracy at 89% but achieved a commendable F1 score of 88.6%. While DenseNet and EfficientNetB7 also showed strong performance, MobileNet emerged as the most effective solution for automated crop disease detection tasks. These results underscore the potential of deep learning models in automating crop disease detection tasks, providing accurate and efficient solutions to address critical challenges in modern agriculture.

BACKGROUND

Overview of Crop Diseases

Crop diseases can be categorized into the following three main types, as shown in Fig. (**1**):

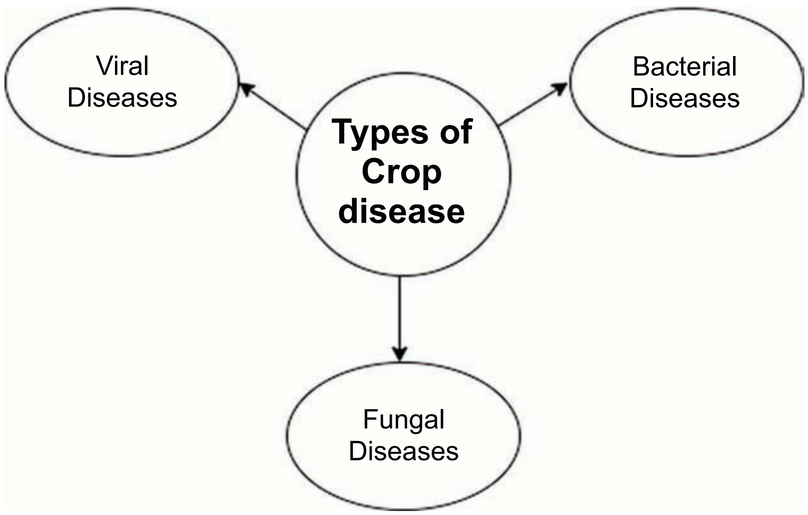

Fig. (1). Classification of crop diseases.

- **Fungal Diseases:** One of the most frequent causes of plant illnesses is fungus. Anthracnose, leaf spot, rust, and powdery mildew are a few examples of fungal infections.
- **Bacterial Diseases:** Bacterial infections have the potential to seriously harm crops. Under ideal environmental circumstances, they can spread quickly and frequently infect plants through wounds or natural openings. Citrus canker, bacterial wilt, and bacterial blight are a few types of bacterial illnesses.
- **Viral Diseases:** Viruses are microscopic pathogens that can produce a variety of symptoms in plants, such as deformation, stunting, and leaf mottling. Vectors like insects, nematodes, or contaminated seeds or plant material are frequently used to spread viral infections. Necrosis viruses, mosaic viruses, and leaf curl viruses are a few types of viral illnesses.

Fig. (**1**) depicts the various types of diseases in crops.

CHAPTER 4

Nanotechnology in Agriculture: A New Frontier

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Abstract: The integration of nanotechnology in smart agriculture presents a transformative approach to addressing global food security challenges and sustainable farming practices. Nanotechnology offers innovative solutions, including nanosensors, nanofertilizers, and nanopesticides, that enhance crop yield, reduce resource consumption, and minimize environmental impact. Nanosensors enable precise monitoring of soil conditions, crop health, and environmental factors, facilitating data-driven decisions that optimize agricultural inputs. Nanofertilizers and nanopesticides ensure targeted delivery of nutrients and crop protection agents, reducing waste and preventing pollution. Additionally, nanomaterials in smart agricultural systems can improve water management, enhance the efficiency of photosynthesis, and promote sustainable farming practices. Thus, this chapter examines the current advancements and potential future applications of nanotechnology in agriculture, highlighting its role in advancing precision agriculture, enhancing food security, and promoting sustainable agricultural practices.

Keywords: Nanotechnology, Nanoparticles, Sensors, Smart agriculture.

INTRODUCTION

Recent advances in microtechnology and Micro-electro-mechanical Systems (MEMS) have necessitated the elucidation of flow and transport processes in small dimensions. This is also the case with several other industrial applications, which rely on low-pressure conditions.

Sustainable agricultural techniques are essential to meet global food demand without compromising the environment and human health. Growing crop diseases, pest problems, and the use of pesticides have aggravated the decline in crop production, and land degradation in agriculture has become a huge global

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challenge [1]. Annual losses in crop production, such as potatoes, corn, peanuts, and soybeans, due to pathogen contamination are estimated to be 10–25% [2]. Nowadays, nano-based systems are proving beneficial for enhancing crop yield and providing more nutritional value while minimizing inputs. Nanotechnology is an interdisciplinary field that studies materials at the nanoscale, allowing for the development of nanomaterials with innovative physical, chemical, and mechanical characteristics by transforming bulk materials [3]. This emerging technology has the potential to address several limitations found in conventional products, including cost, functionality, fabrication methods, and overall performance. Consequently, it presents vast opportunities across various sectors, including food processing, medicine, materials science, agriculture, pharmaceuticals, energy technologies, and electronic devices [4, 5].

Nanoparticles enhance the capabilities of bio-based nanosensors, nanopesticides, and nanofertilizers by providing larger reaction sites, elevating adsorption capacity, and increasing the surface-to-volume ratio [6]. Nano-biosensors or nano-based delivery systems have the potential to impact production without using toxic chemicals. With nanotechnology, it is easier to reduce the bulk volume of chemical fertilizers while improving agricultural growth [7, 8]. While these technological advancements have been crucial for human development, their rapid adoption has brought crop production close to its maximum potential.

Nanoparticle (NP) fertilization and pesticides are crucial techniques used to reduce soil pollution caused by the overuse of chemical-based fertilizers [9]. This approach enables the controlled release of key nutrients while minimizing both biotic and abiotic stresses on plants. The Indian government's launch of nano-sized urea and sulfur-coated urea (Urea Gold) has improved urea release, enhancing nitrogen absorption by 40%. Urea Gold also increases soil sulfur content, which improves plant growth, seed yield (especially in oilseeds), and overall quality. Nanofertilizers offer a promising route toward more sustainable and efficient agriculture [10].

The role of Nanoparticles (NPs) in seed germination is currently under investigation. Since nutrients are essential for plant growth, nanomaterials can enhance seed germination [11]. NPs can also reduce bacterial effects in fields, helping to prevent biotic stress in plants. Several application methods have been discussed in the literature, including seed priming and foliar spraying [12]. Most applications of nanomaterials focus on improving efficiency and productivity in agriculture, aiming to reduce reliance on chemical plant protection additives while enhancing overall crop yield.

Smart agriculture is a farming approach that leverages modern technologies to improve both the quantity and quality of agricultural produce while minimizing environmental degradation [13]. Technologies such as remote sensing, satellite systems, effective yet safe pesticides, and advanced biosensors for soil health monitoring should be utilized. This review focuses on recent advancements and future prospects of nanoparticles, nanofertilizers, nanopesticides, and nanosensors in the field of agriculture.

NANOTECHNOLOGY AND SMART AGRICULTURE

To meet increasing agricultural demands, the advancement and application of innovative techniques are essential. Nanotechnology, a rapidly expanding field, is being integrated into various sectors, including agriculture, to enable precision farming [14]. Applications include the development of nanoparticles, nano/biosensors, nanopesticides, nanofertilizers, and the genetic modification of crops and livestock (see Fig. **1**).

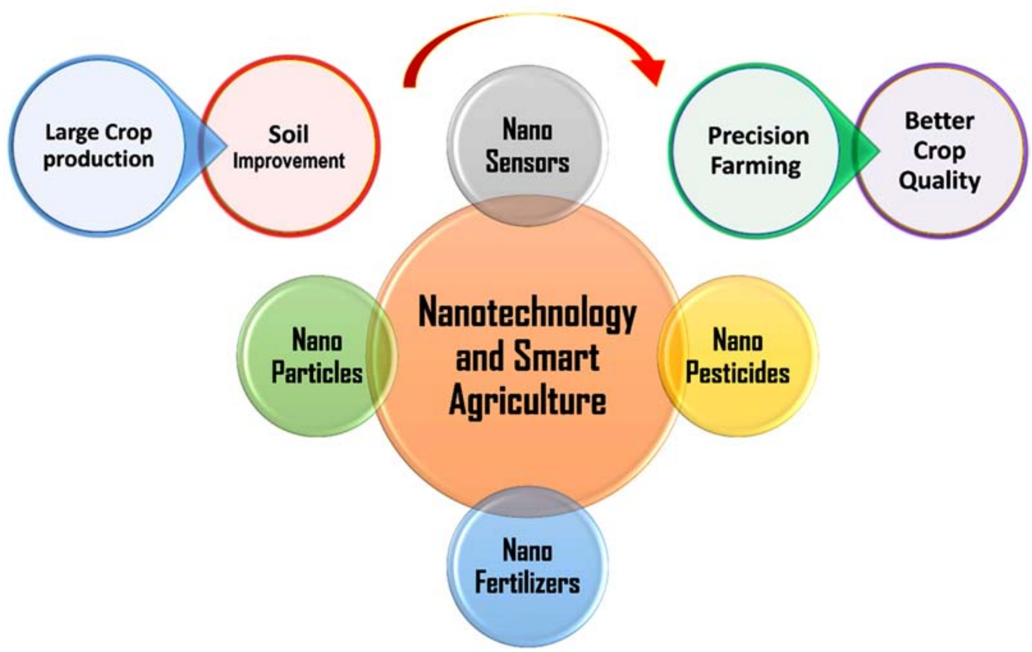

Fig. (1). Smart agriculture applications including nanoparticles, nanosensors, nanopesticides, and nanofertilizers.

Nanomaterials play diverse roles, including improving farm management, enhancing plant nutrition, and protecting against pests and diseases. The concentration of nanoparticles can significantly influence plant germination and

CHAPTER 5

Harnessing Smart Technology for Optimized Livestock Farming: A Comprehensive Overview

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Abstract: This chapter provides a detailed overview of smart technologies used in livestock farming, including automation, robotics, data analytics, Internet of Things devices (IoT), and sensor technologies. It begins by defining and summarizing the smart technologies and highlighting their importance in modern livestock management to improve productivity, health management, animal welfare, and efficiency. The objectives and parameters of the chapter are outlined, with a focus on investigating various technological remedies and their consequences for livestock management. The IoT devices and sensor technology section provides readers with an overview of the concepts behind the use of IoT devices and sensor technology, as well as examples of their various applications in environmental and animal health monitoring, livestock management, and operations. The use of automation and robotics in livestock farming is examined, with an overview of their role in agriculture and specific applications in animal handling, feeding, milking, and waste management. In a nutshell, this chapter covers the opportunities and challenges of smart farming along with case studies.

Keywords: Sensor technology, Animal handling, Automation and robotics, IoT devices, Livestock management, Livestock health monitoring, Smart technology.

INTRODUCTION

Livestock farming can be described as one of the many essential parts of agricultural development and also contributes to the world's food system. It encompasses the breeding and management of domesticated animals, such as cattle, sheep, goats, and other birds and livestock, all to produce various resources, including meat, milk, wool, and eggs. The importance of livestock farming is felt not only in terms of meeting the nutritional requirements, but it also contributes to the wealth creation of a vast number of people across the globe, with special emphasis on rural areas.

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In recent decades, changes have occurred, and trends and patterns have evolved, characterized by the development of breeding, improvement in zootechnics and veterinary medicine, leading to growth marked by high productivity and efficiency. The modern trend in livestock husbandry is to enhance production efficiency while ensuring the humane treatment of animals used for production.

The livestock sector has also undergone significant changes in its adoption of technology. Some of these innovations include the incorporation of automatic feeding, health devices, ordering systems, and analytics, all of which have transformed the sector, making it more productive and effective. Such technological development has not only enabled livestock management to be more effective but has also improved the quality of the products consumed.

LITERATURE REVIEW

This section summarizes the structured review of livestock management, technologies, and tools, as well as sensor technologies and wearable devices used for monitoring, health management, and operations in livestock farming.

In precision Livestock farming, the management of livestock is a significant concern, and the involvement of multiple available technologies can somewhat reduce the human effort required to manage basic tasks. It also involves multiple tools and technologies, such as surveillance cameras [1], wireless communication devices, microphones, and other sensors [2], to collect various types of data in real-time from each animal for a decision support system [3, 4]. The grazing pattern and behavior of livestock are monitored through localization technology, which tracks the movement of cattle on the farm and their grazing patterns, aiding in pasture management [5].

Several studies have focused on the behavioral patterns of livestock [6 - 9]. The RGB cameras are used for the automated detection and measurement of feed intake in individual bovines on the livestock farm [10]. It helps farmers effectively manage expenses and feed requirements using advanced algorithms.

Rodenburg *et al.* [11] proposed an algorithm based on point cloud data and depth images for teat detection and localization. The research is also published for other vision-based technologies, including stereovision techniques and thermal imaging [12], as well as the Haar Cascade classifier using data from structured light depth imaging [13]. The research challenge is to design a standard milking cluster device suitable for all bovines, as there is variability in the shape of the udder and stage of lactation. Table **1** shows the technological advancements and research in the field of automated livestock management. The review primarily focuses on precision livestock farming, wearable technologies, and IoT devices.

Table 1. Research and technological overview in livestock management.

Citation	Application Area	Tools & Technologies Used	Objective of the Research
[5]	Behavioral Monitoring	Localization Sensors	Track the location and grazing patterns of livestock for effective pasture management.
[6]	Behavioral Monitoring	IoT sensors with a localization sensor (GPS)	Behavioral study of discrimination between various types of feeding systems for the classification of behavioral patterns in grazing of animals.
[7]	Behavioral Monitoring	IoT sensors in a neck collar	Behavioral analysis of feeding, rest, and detection of estrus events with rumination rate.
[8]	Health monitoring	Noise sensor	Cough sound analysis for the detection of respiratory diseases in bovines.
[9]	Animal Behavior Analysis	Camera and microphone sensors	Sound signal analysis and correlation of the behavior and sound.
[12 - 14]	Automated System	Thermal and depth Image Analysis using multiple techniques	Teat detection and localization for the automated milking system or robotic system in livestock farms.
[15]	Health monitoring	Image Analysis	Automated detection of lameness of the bovines in dairy farms.

SIGNIFICANCE OF LIVESTOCK FARMING

Livestock farming is important for several reasons, which are as follows:

- Food Production: It helps ensure food security as it is a significant source of protein, vitamins, and minerals through meat, dairy, and eggs.
- Economic Impact: Livestock makes a positive contribution to the rural economy through job creation in farming, processing, and distribution, as well as providing income for several families.
- Cultural Heritage: Several communities have traditions associated with the rearing of livestock that have become integral to their diets, practices, and social organization.
- Soil Health: Properly controlled grazing may benefit soil quality and structure, encourage biodiversity, and improve ecological functions.
- Waste Management: By-products of crop farming can be utilized by livestock, and these wastes can be put to good use, such as manure for fertilizers.
- Climate Considerations: Although livestock systems are a source of greenhouse gas emissions, integrated and sustainable livestock systems, such as rotation grazing and feeding programs, can mitigate their impact.

CHAPTER 6

Blockchain and IoT for Smart Agriculture: Enhancing Food Security and Sustainability

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Abstract: The amalgamation of Blockchain and the Internet of Things (IoT) is presently revolutionizing the agriculture domain, proffering unmatched prospects to augment food security, traceability, and sustainable farming methodologies. This chapter explores how various technologies work together to transform agriculture, tackling important issues such as the requirement for precision farming, inefficiencies in the supply chain, and data management. It begins by outlining the core concepts of blockchain technology and emphasizing the importance of maintaining the integrity and transparency of agricultural transactions and data. Next, the chapter examines how Deep Learning processes the data generated by IoT devices, enabling predictive analytics for crop health, yield optimization, and effective resource management. The chapter also discusses how the Internet of Things (IoT) facilitates a data-driven and flexible agricultural ecosystem by enabling real-time monitoring and management of farm environments. This chapter shows how the integration of Blockchain and IoT simplifies agricultural operations, fosters stakeholder trust, supports environmental sustainability, and creates a more robust and effective food supply system through case studies and theoretical debates. The chapter concludes with an outlook on the challenges and potential paths ahead in utilizing these technologies for advanced smart agriculture.

Keywords: Blockchain, Crop health, Data management, Food security, Internet of Things, Precision farming, Predictive analytics, Sustainable farming, Smart agriculture, Supply chain inefficiencies, Yield optimization.

INTRODUCTION

The emergence of Industry 4.0 has led to the development of revolutionary technologies, one of which is the Internet of Things (IoT). The Internet of Things (IoT), especially in its industrialized form known as Industrial IoT (IIoT), is transforming the banking, manufacturing, healthcare, and transportation industries by allowing objects to interact with one another on their own and supporting more

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effective decision-making processes [1]. The Industrial Internet of Things (IIoT) offers a new paradigm for industrial operations by bridging established industrial processes with cutting-edge technology, including smart sensors, robotics, machine-to-machine communication, big data analytics, and artificial intelligence.

The supply chain industry represents one of the most significant applications of the Industrial Internet of Things (IIoT) [2]. Supply chains offer significant advantages as they evolve into increasingly automated and sophisticated networks, particularly in the fast-paced modern world, where efficiency and transparency are crucial requirements [3, 4]. Concerns regarding product quality and safety within food supply chains are becoming more widespread among consumers, particularly in light of the growing trend toward organic food. These days, consumers want thorough information on the food they eat, including details about hormone changes, pesticide use, and the product's entire path from farm to table.

Maintaining the documentation of a food item's journey, including its creation, processing, distribution, and consumption, is a critical function of a Food Supply Chain (FSC) [5]. Typically, barcodes or RFID tags are used in FSCs to gather data, with the agricultural, food processing, and distribution sectors being the primary sources of this information. Supply chain authorities are placing a greater emphasis on delivering accurate information to establish credibility and foster confidence, as customer expectations for food quality and transparency continue to rise.

Regulatory agencies have implemented guidelines to improve the transparency and traceability of food supply chains in response to these requests. A significant transition from distributed to centralized systems is now underway, driven by the need for enhanced storage capacity, scalability, and fault tolerance. Designing a food supply chain from a logistical standpoint entails addressing intricate hierarchical placement challenges. Recent research has examined bi-level location and size concerns as well as network designs with many linked levels *via* hubs [6 - 8].

Within this framework, blockchain technology presents itself as a viable means of securely exchanging data across decentralized networks, providing a strong foundation for guaranteeing the transparency and integrity of food supply chains.

Internet of Things (IoT) in Industry 4.0

Industry 4.0 facilitates the integration of all technologies to such an extent that equipment functions independently, and intelligent decision-making also takes place. The Industrial Internet of Things primarily impacts industries such as manufacturing, healthcare, transportation, and finance, as it integrates conventional industrial processes with modern technologies, including smart sensors, robotics, machine-to-machine communication, big data, and artificial intelligence. The IIoT enables the development of integrated and more efficient systems, increasing production efficiency and operational visibility. This trend is most vivid in supply chain management, where IIoT technologies are now being developed to form networks that enhance processes that traditionally required labour and were deemed tedious and impossible to perfect.

Blockchain and Explainable AI in Smart Agriculture

Blockchain enables customers to obtain trustworthy information on the provenance, quality, and safety of food items by preserving unchangeable production process records. Simultaneously, Explainable AI [7] enhances intelligent agriculture decision-making by providing comprehensible insights into AI-driven recommendations, thereby building confidence among farmers and other stakeholders.

Explainable AI and blockchain technology [8, 9] can be leveraged to enhance smart agriculture, highlighting how these innovations have the potential to completely transform the industry by ensuring sustainable practices, traceability, and accountability [10].

In the development of smart agriculture, blockchain technology and Explainable Artificial Intelligence (XAI) are becoming increasingly potent instruments. Blockchain addresses issues with traceability, accountability, and food safety by providing a decentralized, transparent, and safe platform for data recording and sharing throughout the agricultural supply chain [11]. In smart agriculture, the integration of XAI and blockchain not only increases operational effectiveness but also promotes more ecologically friendly and sustainable farming methods [12]. This convergence of technologies is poised to revolutionize the agricultural sector, making it more resilient, transparent, and consumer-focused.

This chapter aims to examine how Industry 4.0 technologies, particularly the Industrial Internet of Things (IIoT), are revolutionizing several sectors, with a special emphasis on the supply chain. The chapter examines how the Internet of Things (IoT) can enhance the openness, efficiency, and decision-making capabilities of food supply chains while meeting the increasing expectations of consumers for product quality and safety.

CHAPTER 7

Enhancing the Tomato and Potato Crop Health: A Novel Approach for Ensemble Deep Learning based Disease Classification

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Abstract: The primary goal of this chapter is to study the current research in order to detect diseases in tomato and potato crops through the analysis of leaf images. We propose a novel methodology that involves a comprehensive data preprocessing stage, including image resizing and augmentation to enhance the dataset. We study the various pre-trained transfer learning architectures that can be used for classification. In this chapter, we discuss three ensemble models based on the best-performing architectures. Model 1 is a generalized model for both tomato and potato plants, Model 2 is specialized for potato plant diseases, and Model 3 focuses on tomato plant diseases. These ensemble models utilize a weighted average approach to calculate the results. The combination of these models is based on the highest-performing individual base models, ensuring optimal performance. The highest accuracy achieved for potato plant disease identification is 99.06%, while the best accuracy for tomato plant disease identification is 98.12%. The chapter studies and explores the efficacy of ensemble deep learning models in classifying plant diseases with accuracy, offering a robust tool for agricultural disease management.

Keywords: Crop health, Disease detection, Deep learning, Ensemble learning, Transfer learning.

INTRODUCTION

Agriculture has always been a crucial means of livelihood. The Indian economy is heavily dependent on the agricultural industry of the country [1]. It plays a great role in providing employment as well as food security for a large section of people [2]. It is a vital industry for the Indian economy, employing around 58% of

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the workforce and adding about 17% to the country's GDP. Tomatoes and potatoes are among the most significant crops globally, providing vital nutrients and serving as the backbone of many farming communities worldwide [3].

However, plant disease has a detrimental impact on these crops, affecting their productivity and quality [4]. Microorganisms, infectious agents such as viruses, fungi and bacteria, and genetic abnormalities are the main contributors to these diseases [5]. Crop diseases cause significant financial losses that impact the entire economy [6]. The variations in the demand and distribution network of agriculture-based consumables affect the overall balance of the economy [7]. Thus, timely identification and diagnosis of crop diseases are essential for optimal production. Traditional methods of classifying plant diseases included the visual examination of plant tissues by skilled professionals, but this approach was inefficient, expensive, and time-consuming [8]. The results of the visual approach were affected by subjectivity and resulted in the inaccuracy of the disease identified [9, 10]. In recent years, advances in computer technology, particularly in Artificial Intelligence (AI) and image processing approaches, have made the identification and diagnosis of crop diseases possible at an early stage. This is an automated procedure that can be used in fields and farms [11].

The various existing studies have proposed different models using machine learning, deep learning, and hybrid methodologies for accurate and efficient crop disease classification. Early machine learning models often relied on handcrafted features and classical algorithms. Deep learning models, particularly CNN's apply automatic feature extraction from raw images and hybrid models use the strengths of both ML and DL techniques. Despite these advancements, several challenges remain. So, there is a need for a novel approach that can further enhance the classification of tomato and potato crops with more accurate results. The present study proposes the weighted average ensemble model by combining the top-performing pre-trained deep learning models that are fine-tuned using the Plant Village dataset. This approach aims to integrate the capabilities of multiple models to increase the accuracy and robustness of disease detection. By integrating these models, the ensemble method can better generalize, addressing the limitations of individual models and improving the results of existing studies.

The remaining sections of the chapter are structured as follows: Section 2 discusses the existing work along with an overview of plant diseases. Section 3 provides detailed insights into the materials and methods employed in the study, including a dataset description, proposed methodology, implementation details and evaluation metrics. In Section 4, the experimentation results are presented. Finally, Section 5 wraps up the chapter by highlighting essential findings, discussing the implications and possible directions for future studies.

BACKGROUND

Overview of Plant Diseases

Plant diseases significantly affect crop health and productivity, which causes agriculture to suffer huge economic losses. These diseases can be broadly divided on the basis of biotic and abiotic causes as shown in Fig. (**1**) below, each of which has a special role in the pathology of plants [12]. To create effective disease management strategies and ensure sustainable farming practices with significant yield, understanding these factors is essential.

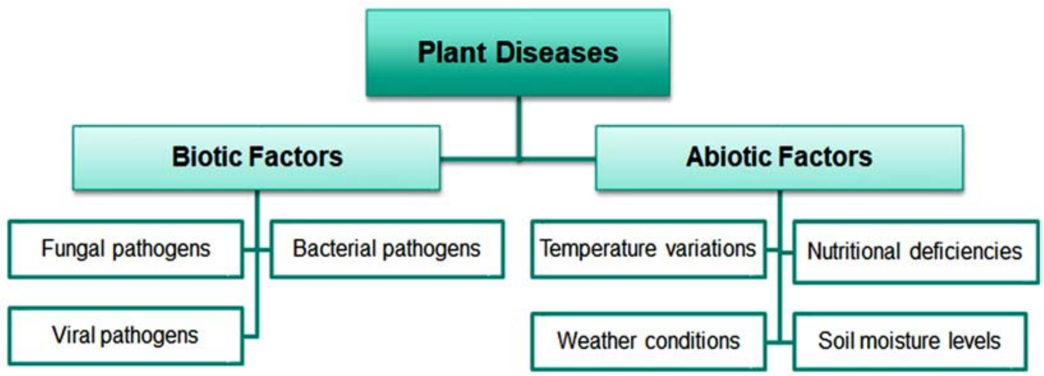

Fig. (1). Causes of plant diseases.

1) Biotic Factors include the living organisms that infect plants and cause the development of diseases. These include:

- **Fungal pathogens:** Fungal infections are characterized by spots, rust, blights, and powdery mildews affecting the stems, leaves and fruits of plants. For example, early blight in potato, and septoria leaf spot in tomato.
- **Bacterial pathogens:** Bacterial infections result in leaf spots, wilts, and soft rots, causing damage to plant tissues. For example, bacterial spots in tomatoes.
- **Viral pathogens:** Viral infections cause symptoms like mottling, stunted growth, leaf curl, and yellowing, and reduce the productivity of plants— for example, the yellow leaf curl virus in tomatoes.

2) Abiotic Factors involve environmental conditions that lead to the development of illnesses in plant species.

- **Temperature variations:** Create physiological stress in plants, can harm their tissues and can inhibit their growth.
- **Nutritional deficiencies:** Lack of vital nutrients can lead to yellowing of leaves, stunted growth and death of plant tissues.
- **Weather conditions:** High humidity can cause fungal growth.
- **Soil moisture levels:** Plant health can be adversely affected by both

CHAPTER 8

The use of Big Data, Deep learning, IoT, and Blockchain in Livestock Management

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Abstract: Livestock management is a crucial aspect of agriculture, impacting both the economy and food security worldwide. Traditional methods of monitoring and managing livestock have often been labour-intensive and inefficient. This chapter investigates the transformative impact of Big Data, Deep Learning, Internet of Things (IoT), and Blockchain in the field of livestock management. In recent years, these technologies have revolutionized traditional agricultural practices, providing a holistic approach to ensuring the well-being and productivity of livestock. Big Data analytics play a critical role in collecting and analysing massive datasets from animal-connected sensors and wearables attached to animals, providing farmers with valuable insights into health, behaviour, and environmental conditions. Deep Learning algorithms help automate tasks. such as real-time monitoring, disease detection, and behavioural analysis, leading to proactive interventions for individual animal welfare and the overall health of the flock or herd. The integration of IoT devices creates an interconnected network, enabling the accurate monitoring of animal parameters and environmental factors, thereby optimizing feeding, breeding, and disease control.

Furthermore, blockchain technology ensures transparency and traceability in the livestock supply chain, promoting trust between stakeholders and consumers by recording critical information on the origin, health, and ethical treatment of animals. This chapter presents current research and technological advances, offering a comprehensive exploration of the applications of Big Data, Deep Learning, IoT, and Blockchain in livestock management as mentioned. By examining the synergy between these technologies and their collective impact on livestock welfare, productivity, and sustainability, this work contributes to the growing body of knowledge aimed at advancing modern agricultural practices in the livestock farming sector.

Keywords: Blockchain, Big data analysis, Deep learning, Internet of things, Livestock management.

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INTRODUCTION

Livestock management is the cornerstone of sustainable agriculture, encompassing diverse practices that optimize the care, productivity, and welfare of domesticated animals. At its core, it involves the art and science of tending to various species, such as cows, goats, sheep, pigs, and poultry, to meet both human needs and animal well-being. From nutrition and healthcare to breeding and marketing, effective livestock management requires a multifaceted approach that balances practical skills, scientific knowledge, and ethical considerations.

Central to livestock management is the commitment to ensuring the health and vitality of animal populations while maximizing their productivity in an environmentally responsible and economically viable manner. Blockchain technology is being implemented in various ways in livestock farming [1]. Through proper nutrition, shelter, healthcare, and breeding practices, livestock managers play a vital role in sustaining the livelihoods of farmers and ranchers, as well as the global food supply chain.

The efficiency, monitoring, and general welfare of animals have been greatly increased with the use of cutting-edge technologies in livestock production. Ji *et al.* [2] investigated how heat stress affected milking and rumination in robotic dairy farms, highlighting the necessity of exact environmental management. Neethirajan and Kemp [3] emphasized how digital cattle husbandry may increase productivity by using automated decision-making and real-time monitoring. Dewangan and Vij [4] presented a self-adaptive edge computing architecture that uses IoT and AI to optimize cattle management in the context of technological developments. According to Kampan *et al.* [5], the use of blockchain technology has also improved the security and traceability of animal products. By establishing a secure cattle stock, Leme *et al.* [6] further emphasized the significance of blockchain.

As we navigate the complexities of modern agriculture, livestock management principles guide us in fostering resilience, efficiency, and sustainability in animal husbandry practices worldwide. Many commercial firms are actively developing and producing robots that can automatically check the atmosphere of cattle farms [7]. In this case, Big Data, Deep Learning, and Blockchain technologies [8, 9] are used to enhance the efficiency of its operations.

Overview of Livestock Management Practices

Livestock management encompasses a rich tapestry of traditional wisdom and modern innovations designed to ensure the health, productivity, and welfare of domesticated animals. Traditional methods, rooted in centuries of agricultural heritage, often emphasize close observation, hands-on techniques, and an intimate understanding of the natural rhythms and needs of livestock species. Practices, such as rotational grazing, where animals are moved regularly between pastures to optimize forage utilization and soil health, have been passed down through generations, promoting sustainable land management and biodiversity conservation.

In contrast, modern livestock management integrates cutting-edge technologies and scientific advancements to enhance efficiency, precision, and scale. Innovations such as precision nutrition, which utilizes data-driven approaches to tailor diets to individual animal requirements, and automated monitoring systems that track animal health metrics in real-time represent just a glimpse of the transformative potential of modern methods. Additionally, genetic selection and breeding programs harness the power of genomics to accelerate livestock development, incorporating traits, such as disease resistance, growth rate, and product quality, thereby driving improvements in overall productivity and profitability.

However, while modern methods offer unprecedented opportunities for optimization and productivity gains, they also raise important considerations around animal welfare, environmental sustainability, and societal values. Traditional wisdom often emphasizes holistic approaches that prioritize the well-being of animals and the health of ecosystems, reminding us of the interconnectedness of all living beings within agricultural systems. As we navigate the complexities of livestock management in the 21st century, there is a growing recognition of the need to integrate the best of both worlds – drawing on the wisdom of the past while embracing the innovations of the future – to forge a path toward a more resilient, equitable, and sustainable agricultural future. Finding a harmonious balance between traditional and modern methods holds the key to unlocking the maximum potential of livestock management in meeting the evolving needs of humanity while safeguarding the planet's health for generations to come. There is a significant impact of heat stress on animal behavior and the efficiency of robotic milking machines.

Modern advances, fueled by cutting-edge technologies and scientific breakthroughs, coexist with traditional methods rooted in millennia of agricultural wisdom to form the dynamic field of livestock management. An emphasis on holistic strategies, such as rotational grazing and selective breeding, is placed on traditional methods rooted in a deep understanding of animal behavior and natural ecosystems, with a focus on maximizing productivity while preserving environmental sustainability and animal welfare. On the other hand, modern techniques utilize instruments such as genetic selection, automated monitoring

CHAPTER 9

Next-Gen Precision Agriculture: Integrating AI, IoT, and D2D Communications

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Abstract: This chapter explores the synergistic integration of Artificial Intelligence (AI), the Internet of Things (IoT), and Device-to-Device (D2D) communications within the context of precision agriculture, a pivotal innovation aimed at enhancing farming efficiency and real-time decision-making. As global demands for food increase and the need for sustainable agricultural practices becomes more urgent, the convergence of these technologies offers a transformative solution. AI's capability for sophisticated analytics allows for predictive insights and enhanced decision-making. Concurrently, IoT devices facilitate comprehensive real-time data collection across various agricultural environments, and D2D communications ensure robust, immediate data exchange, which is crucial for operational efficiency and prompt responses in agricultural settings. The chapter outlines the applications, benefits, and challenges associated with implementing these technologies in agriculture. It discusses how AI-driven systems enhance crop monitoring and soil management, how IoT networks facilitate extensive data acquisition, and how D2D communications improve connectivity and system reliability. Furthermore, it addresses the integration challenges such as interoperability, security, and privacy, and proposes a framework for overcoming these barriers through standardization and best practices. Future directions, such as the implications of 5G technology and advanced AI models on agriculture, are also explored to highlight ongoing research and emerging opportunities. This comprehensive analysis not only underscores the significant enhancements that AI, IoT, and D2D technologies bring to precision agriculture but also emphasizes the necessity for continued innovation and interdisciplinary collaboration to realize their potential in modern farming practices.

Keywords: Artificial intelligence, Agricultural technology integration, Device-to-device communication, Internet of Things (IoT), Precision agriculture.

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INTRODUCTION

In the face of an ever-expanding global population and the consequent rising demand for food, modern agriculture stands at a critical juncture. The necessity to enhance yield and efficiency while minimizing environmental impacts presents a formidable challenge that traditional farming methods alone are ill-equipped to tackle. Enter the transformative trio of technologies: Artificial Intelligence (AI), the Internet of Things (IoT), and Device-to-Device (D2D) communications. Together, these innovations promise to revolutionize agricultural practices by ushering in an era of precision agriculture that is both sustainable and highly productive [1].

Artificial Intelligence (AI) serves as the brain of this technological triad, offering unparalleled data analysis capabilities that enable predictive insights and decision-making processes far beyond human speed and accuracy [2]. By integrating AI, the agricultural sector can leverage machine learning models to predict crop yields, optimize resource allocation, and manage risks more effectively [3].

The Internet of Things (IoT) acts as the nervous system, providing a network of sensors and devices that continuously collect and transmit data from the field. This real-time data collection enables immediate and precise responses to varying crop needs, soil conditions, and environmental factors [4]. IoT technologies enable remote monitoring and management of agricultural environments, ensuring optimal conditions for plant growth and reducing the need for manual labor [5].

Device-to-Device (D2D) communication serves as the primary link within this ecosystem, enabling direct interactions between devices on the farm. This capability enhances operational efficiency by reducing reliance on centralized networks, which can be prone to delays and failures [6]. D2D communication facilitates the deployment of autonomous agricultural machinery, including drones and robots, thereby further automating farming practices and reducing human workload [7].

The convergence of AI, IoT, and D2D technologies not only elevates the capabilities of each technology but also harmonizes their functionalities to create a cohesive, integrated system. This synergy optimizes agricultural processes, from seeding to harvesting, and ensures that every resource is utilized to its maximum potential. The resulting precision agriculture system can significantly increase crop yields, decrease waste, and minimize the environmental footprint of farming activities.

This chapter aims to explore the integration of these cutting-edge technologies within the realm of precision agriculture. It will discuss their individual and collective contributions to farming efficiency, delve into the challenges they face, and provide insights into future directions for this exciting field. By harnessing the power of AI, IoT, and D2D, the agricultural sector can not only meet the increasing food demands of a growing population but also ensure that farming remains sustainable for future generations. (Fig. **1**) illustrates the architecture of the AI, IoT, and D2D framework used in agriculture.

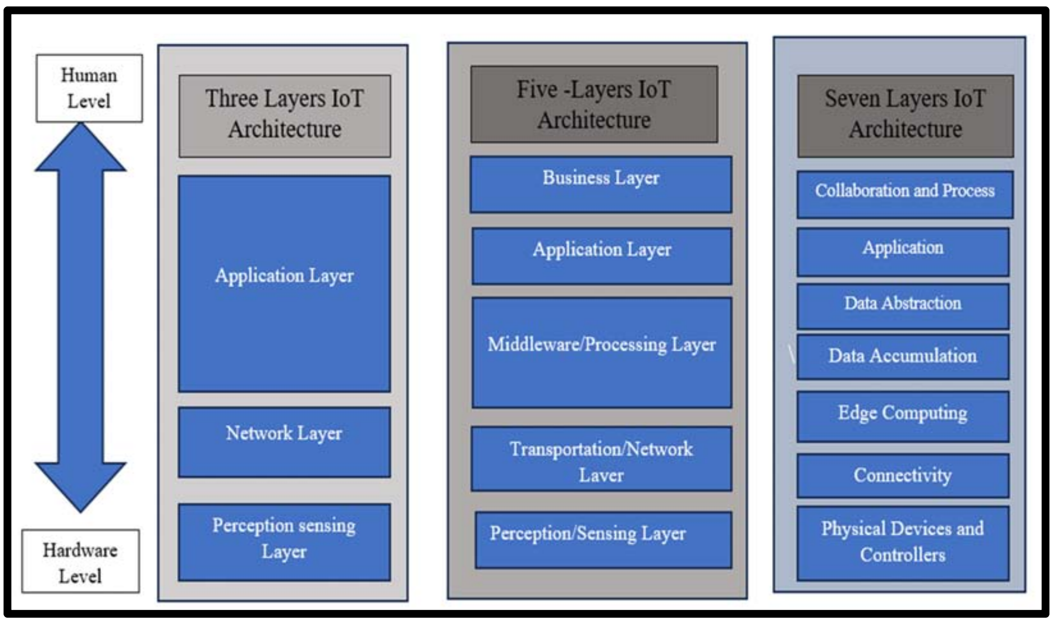

Fig. (1). Conceptual framework of AI, IoT, and D2D in agriculture.

Visual representation of the data flows and interactions between AI, IoT, and D2D devices in an agricultural setting [4].

TECHNOLOGICAL BACKGROUND

As the global agricultural sector faces the dual challenges of increasing productivity and reducing environmental impact, the strategic integration of Artificial Intelligence (AI), the Internet of Things (IoT), and Device-to-Device (D2D) communications emerges as a critical solution. This section provides a foundational understanding of these technologies, their specific applications in agriculture, and how their interplay fosters enhanced efficiency and precision in farming operations.

CHAPTER 10

The Role of Big Data and Deep Learning in Crop Management

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Abstract: The integration of big data and deep learning technologies has brought about a paradigm shift in crop management practices, offering innovative solutions to address the complex challenges faced by farmers and agricultural experts. This chapter explores the pivotal role of big data in collecting, storing, and analyzing vast amounts of agricultural data from diverse sources, such as satellite imagery, sensors, and drones. It highlights how deep learning algorithms leverage this data to provide real-time insights into crop health, soil conditions, and environmental factors, enabling precision agriculture and predictive analytics. Additionally, this chapter discusses how deep learning models facilitate crop monitoring, disease detection, and yield optimization by analyzing image data and forecasting future outcomes. Furthermore, it examines the implications of these technologies on supply chain management and decision support systems in agriculture. Overall, the study underscores the transformative potential of big data and deep learning in revolutionizing crop management practices, fostering sustainability, and enhancing productivity in the agricultural sector.

Keywords: Big data, Crop management, Crop monitoring, Deep learning, Precision agriculture, Predictive analytics.

INTRODUCTION

Agronomy and plant breeding are costly fields that are essential for providing water and ensuring food safety for the earth's growing population [1]. Agriculture is leveraging advancements in big data analytics, genomics, robotics, remote sensing, satellite imagery, and sensor technology.

Farming is the foundation of human society, supplying essential nutrients, fiber, and fuel for nourishment. Efficient crop management is crucial for meeting the increasing global food demand, ensuring food security, and achieving sustainable

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agricultural practices. In recent years, advancements in technology have revolutionized crop management, with big data and deep learning emerging as transformative tools. The term “big data” refers to the vast amount of data collected from numerous sources, characterized by its high volume, diversity, and complexity. As a branch of artificial intelligence, deep learning entails teaching neural networks to identify patterns and draw conclusions from massive amounts of data. Together, these technologies offer unprecedented opportunities to enhance crop management practices by enabling precise, data-driven decisions. This chapter examines the intersection of big data and deep learning in crop management, exploring their roles, applications, and future potential in transforming the agricultural sector.

Agriculture, the primary consumer of water at 85%, often suffers from inefficient usage due to leaky channels, seepage, and evaporation, while inadequate irrigation can stress crops [2]. Soil moisture is influenced by rainfall, soil quality, climate, and vegetation. Efficient water management is essential for water conservation and optimal crop yields. Several factors, including soil salinity and inadequate soil management, impact crop growth. Farmers need advanced information to provide precise irrigation. It is essential to evaluate crop attributes, including moisture levels in the soil at various layers.

Tools and technology for hyperspectral and multispectral analysis have shown promise for enhancing food production and methods by providing producers and crop planners with insights into crop health and development [3]. Agricultural big data technology addresses the issues of the new data era [4]. Farmers can utilize machine learning to address issues related to decision-making, water and soil management, crop management, and animal management. Crop management involves predicting yields, detecting diseases and weeds, assessing crop quality, and identifying species. Livestock management focuses on both animal care and production. Designing agricultural big data systems is challenging due to the need to adjust technology and adapt deep learning approaches as data volumes increase.

Crop protection, crucial for preventing crop yield losses, entails controlling insects, weeds, and plant diseases [5]. The development of resistance to herbicides has made weed control more difficult. New developments, such as the IoT, allow farmers to gather enormous amounts of data from sensors that monitor crops, water, and soil; this increases productivity and reduces dangers from pests and illnesses. Advanced sensing techniques, including RGB, thermal, NIR, hyperspectral, and multispectral imaging, are increasingly deployed in smart farming [6]. Advancements in technology are paving the way for digital agriculture, which will benefit plant breeders and agronomists significantly [7]. Blockchain technology holds promise for enhancing data security and transparency in the agricultural sector [8]. Sensors, mounted on drones or satellites, generate large volumes of diverse data requiring efficient storage and analytics solutions. This phenomenon, known as big data, poses challenges due to its volume, variety, and velocity. To address these challenges, the concept of 'big sensor data' is introduced, highlighting its potential in modern agriculture. Numerous agricultural applications, including crop management, yield prediction, disease identification, and monitoring of soil, water, and land, extensively utilize these techniques. In a single acquisition [9], hyperspectral data collection can detect hundreds of spectral bands that comprise the electromagnetic range of an observation situation. A substantial amount of spectrum and spatial details is contained in the resulting hyperspectral information cube.

Deep learning, a fast-growing area of AI, offers scalable and modular strategies for analyzing big data. The combination of deep learning and big data for crop security, supported by intelligent sensing and instrumentation, is expected to transform agriculture and smart farming systems. By leveraging data-driven methods, farmers can refine their decision-making processes [10], ultimately enhancing crop yields and reducing the impact of weeds, pests, and diseases.

Agricultural remote sensing applications face big data issues due to the increased velocity and volume of data generated by hyperspectral images or videos. Big data, machine learning [11], as well as deep learning, have numerous exciting applications in agriculture when it comes to hyperspectral and multispectral data. In the processing of agricultural data, collective neural networks and scalable parallel discriminant analysis have not yet received enough attention. Validation experiments and data analytics have been conducted using hyperspectral data from the agricultural sector [12].

Deep learning has been effectively used to construct decision support systems across numerous fields. Consequently, there is growing interest in applying it to other critical areas, such as agriculture. Total energy consumption in agriculture includes fertilizers, power, chemicals, human labour, and water. Yield predictions are crucial for ensuring food security, managing crop production, scheduling irrigation, and predicting labor requirements for harvesting and storage. Thus, calculating product yield helps decrease energy use.

Effective crop management involves a comprehensive approach that integrates various components to ensure optimal crop growth, yield, and sustainability. (Fig. **1**) depicts the key components required for crop management.

CHAPTER 11

AI-Driven Cybersecurity in Agriculture: The Future of Farming

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Abstract: Digital technologies such as the Internet of Things (IoT), drones, autonomous machinery, and advanced data analytics are quickly revolutionizing the agricultural industry. This digital transformation, known as precision agriculture, has greatly improved productivity, sustainability, and efficiency in farming methods. Nevertheless, the industry is confronted with increasing cybersecurity issues despite these advancements. The growing dependence on interconnected systems has created vulnerabilities that cybercriminals are exploiting more and more, endangering not just individual farms but also the entire food supply chain. This section explores the cybersecurity environment in the agricultural industry, highlighting major risks like phishing, ransomware, data breaches, and industrial espionage. It highlights the importance of strong cybersecurity measures to safeguard the integrity and functionality of contemporary agricultural systems. The chapter emphasizes the crucial importance of Artificial Intelligence (AI) in dealing with these challenges, providing AI-based solutions for identifying threats, automating responses, and safeguarding data. The future success of the agricultural industry's digital transformation relies on protecting its technological infrastructure from cyber threats. This section supports the idea of implementing a holistic cybersecurity plan that includes AI, various security layers, and ongoing education and awareness efforts. Through enhancing its digital progress, the agricultural industry can guarantee continuous expansion, adaptability, and the capacity to fulfill international food requirements in a progressively interconnected globe. The chapter states that the future of agriculture relies not just on technological advancements but also on the industry's dedication to cybersecurity. Ensuring the security of digital agricultural systems is crucial for sustaining global productivity, sustainability, and food security.

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Keywords: Agricultural supply chain, Agricultural technology, Artificial Intelligence (AI), Autonomous machinery, Cybersecurity in agriculture, Cyber risk management, Data analytics in farming, Internet of things (IoT), Precision agriculture, Smart farming.

INTRODUCTION

In the current era of technology, cybersecurity has become increasingly important. Every day, a large number of people and organizations are impacted by various cyberattacks, including phishing, DDoS, password, and data breach attacks. Government, consumers, and organizations using computer networks are all at serious risk from cybercriminals. It has always been difficult to put in place efficient procedures and controls to lessen the likelihood of cyberattacks and other crimes. In this aspect, upholding the highest standards necessitates deliberate effort. The only technologies that are useful in preventing cyberattacks are intelligent ones. Both management and individuals must properly control cyberattacks.

All significant stakeholders, including the government, business community, owners of infrastructure, and end users, have a responsibility to ensure cybersecurity. Governments and multinational organizations are important players in cybersecurity. The agricultural sector is dealing with new prospects and problems as it advances through the use of advanced digital and automated technologies. The switch to "precision agriculture" or "smart farming" is completely changing how we cultivate, tend to, and harvest crops. The evolution is being fueled by technologies like the Internet of Things (IoT) [1], drones, autonomous machines, and advanced data analytics, which promise increased sustainability, productivity, and efficiency.

The deployment of these most recent innovations, however, does enhance vulnerabilities to online dangers. Once thought of as low-tech, the agriculture sector is now facing questions regarding data security, privacy, and the integrity of its digital systems. The rising number of cyberattacks in this industry puts individual farms, the broader food supply chain, and even global food security at significant risk.

"Agri-cybersecurity," or cybersecurity in agriculture [2], is a buzzword that's becoming increasingly significant as the agricultural sector incorporates more automated and digital technologies. Known as "smart farming" or "precision agriculture," this technological integration in agriculture utilises drones, Internet of Things (IoT) devices, autonomous machinery, and data analytics to increase productivity and efficiency. However, as a result of the industry's growing connectedness and reliance on digital tools, cyber risks are also becoming more prevalent.

The agricultural sector can continue to benefit from advancements in technology while safeguarding itself from the increasing possibility of cyberattacks by understanding and addressing these concerns. All parties involved have to collaborate to ensure the sustainability and resilience that characterize modern agriculture. Beyond the immediate safety of data and systems, the implications of cybersecurity in agriculture using AI include ensuring food security, maintaining the integrity of supply networks, and bolstering the overall resilience of agricultural operations. As cyber threats [3] become more sophisticated, the agricultural industry must implement strong AI-driven cybersecurity measures to safeguard its assets and ensure global food systems' stability and expansion.

The present study examines the application of AI technology to enhance agricultural productivity while also mitigating cyberattacks. AI applications are transforming agriculture in a variety of ways, including data analytics, predictive modeling, automated machinery, and precision farming. However, these developments also raise the possibility of cyberattacks, which have the potential to jeopardise important data, cause operational disruptions, and endanger food security.

It is essential to understand how AI (Artificial Intelligence) can be used to improve cybersecurity in agriculture using a combination of theoretical insights and real-world case studies. In this crucial area, responsible AI technology deployment also requires legal frameworks and ethical considerations.

By investigating the intersection of artificial intelligence and cybersecurity, interested parties can acquire the skills and knowledge required to manage the complex processes of modern farming. Ultimately, it emphasizes the importance of developing robust agricultural systems that can withstand the evolving cyber threats of the modern era.

(Fig. **1**) presents the architecture of various devices, applications, and layers that are a part of innovative agriculture systems:

SUBJECT INDEX

A

B

C

Shefali Arora Chouhanm Nagendra Pratap Singh, Banalaxmi Brahma & Shashank Gupta (Eds.)
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D

E

F

G

H

I

K

L

M

N

O

P

Q

R

S

T

U

V

W

X

Y

Z

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