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Advancing Agriculture in Smart Cities: Renewable Energy and Artificial Intelligence-Powered IoT

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Abstract. This paper reviews advancements in vertical farming and smart agriculture technologies, focusing on the integration of Artificial Intelligence (AI) and Internet of Things (IoT) in urban agricultural practices. Vertical farming, propelled by AI and IoT, addresses land and water scarcity in urban settings, offering a sustainable solution by utilizing vertical spaces for cultivation. Smart AgroTech systems in urban farming exemplify the convergence of IoT and renewable energy resources, facilitating efficient farm operations. These systems automate irrigation based on real-time data, providing remote monitoring and control to farmers, thus reducing error margins in farming operations. Furthermore, AI-powered robots and drones are revolutionizing traditional farming landscapes by automating crucial tasks like weeding, spraying, and crop monitoring, conserving resources and augmenting overall productivity and quality of produce. The reviewed studies unveil a shift towards data-driven, automated, and sustainable farming practices crucial for food security in growing urban populations, laying a foundation for future explorations in this interdisciplinary domain.

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1 Introduction

The rapid growth in global population is ushering in a pressing need to address the challenges of food security. These challenges are further intensified by climate change, water shortages, and the diminishing availability of arable land due to urban expansion. This scenario calls for a transformative approach in agricultural practices, steering towards more sustainable and technologically advanced models. Smart farming emerges as a promising solution, encapsulating the integration of modern technologies such as the Internet of Things (IoT), cloud computing, and Artificial Intelligence (AI) to bolster agricultural productivity and sustainability. The smart farming model is not merely a reactive measure to the challenges but a proactive step towards morphing traditional agricultural practices into a modern, precision-based, and intelligent agricultural system.

Vertical farming, a pivotal aspect of urban agriculture, presents a fresh approach to tackle land and water shortages. By utilising vertical spaces for cultivation, it transcends the limitations imposed by urban landscapes. The integration of IoT and AI in vertical farming facilitates a data-driven approach to agriculture, enabling real-time monitoring and intelligent decision-making in various facets of farming such as irrigation, yield prediction, growth monitoring, and disease detection. The fusion of machine learning algorithms with data collected from IoT devices propels the transition from traditional to modern agriculture, epitomising the essence of precision and smart agriculture. The potential of vertical farming extends beyond merely addressing food security; it heralds a new era of intelligent agricultural engineering capable of producing guaranteed quality and quantity of crops irrespective of external adversities such as weather changes or soil conditions.

The application of AI, particularly machine learning and deep learning, in agriculture has been a game-changer. These technologies have the capability to process vast amounts of data, gleaned from various sources, to provide actionable insights. The self-learning nature of machine learning algorithms, coupled with real-time data from IoT devices, creates a robust framework for smart farming. This framework encapsulates the activities defined in smart farming, the datasets utilised, and the machine learning algorithms employed to analyse the features of each activity. The convergence of these technologies not only augments the efficiency and productivity of vertical farming but also opens avenues for further exploration in the realm of specialised or functional food production through environmental control and manipulation.

The broader vision of integrating AI and IoT in agriculture transcends the boundaries of vertical farming and permeates other facets of agriculture, contributing to the larger narrative of smart cities. The proposed IoT-based Smart AgroTech system in the context of smart city farming exemplifies the seamless integration of technology in agriculture, automating irrigation based on real-time data and providing remote monitoring and control to farmers. This technological infusion in agriculture is a stepping stone towards transforming conventional cities into smart cities, aligning with the global trajectory towards technological advancement and sustainability. The narrative of smart agriculture is intertwined with the narrative of smart cities, each reinforcing the other in a bid to create a sustainable, efficient, and technologically driven future. The amalgamation of renewable energy, AI-powered IoT, and innovative agricultural practices like vertical farming, underpins the ethos of smart cities, fostering a symbiotic relationship between urban development and agricultural sustainability.

2 Review and discussion

In a study by Talaviya et al. (2020), the utilization of Robots and Drones in agriculture was explored to understand their impact on modern farming practices [3]. The study delves into how these technologies are revolutionising the agricultural sector by automating various farming operations, thereby enhancing productivity and efficiency. The following tables provide a detailed breakdown of the applications, technologies, and outcomes associated with the use of Robots and Drones in agriculture as discussed in the study.

Table 1. Analysis on Robots in Agriculture [6-8]

Aspect	Description	Technologies/Algorithms Used	Benefits	Challenges/Knowledge Gaps
Weeding	Autonomous robots are employed for weeding operations, replacing manual labour and improving efficiency.	Autonomous Systems, GPS	Increased productivity, reduced labour costs	Integration with other farm operations, cost of deployment
Irrigation	Robots assist in managing irrigation systems ensuring optimal water usage.	Sensor Technologies, GPS	Efficient water usage, timely irrigation	Real-time data processing, sensor accuracy
Monitoring	Robots are used for monitoring farm conditions, ensuring adverse environmental conditions do not affect production.	Sensor Technologies, Machine Learning	Real-time monitoring, early detection of issues	Scalability, data privacy and security
Individual Plant Management	Managing individual plants in various unfamiliar ways to enhance overall farm productivity.	Autonomous Systems, Sensor Technologies	Improved plant health, increased yield	Individual plant recognition, real-time decision making
Pest and Disease Management	Robots help in managing pests and diseases by timely detection	Sensor Technologies, Image Recognition	Early detection and management of pests and	Effective treatment solutions, integration with other systems

	and action.		diseases	

Table 2. Analysis on Drones in Agriculture [9-11]

Aspect	Description	Technologies/Algorithms Used	Benefits	Challenges/Knowledge Gaps
Crop Health Monitoring	Drones are used to monitor crop health and detect issues early on.	Remote Sensing, Image Processing	Early detection of crop health issues, timely intervention	High-resolution imaging, real-time data processing
Irrigation Equipment Monitoring	Monitoring the status and efficiency of irrigation equipment.	Sensor Technologies, GPS	Efficient irrigation, reduced water wastage	Sensor accuracy, real-time monitoring
Weed Identification	Identifying and managing weed infestations in the farm.	Image Recognition, GPS	Effective weed management, increased productivity	Weed species recognition, integration with treatment solutions
Herd and Wildlife Monitoring	Monitoring livestock and wildlife to ensure safety and well-being.	GPS, Remote Sensing	Safety of livestock, monitoring wildlife interactions	Real-time monitoring, animal behaviour analysis
Disaster Management	Employing drones for managing disasters and assessing damage.	Remote Sensing, GPS	Quick assessment and response to disasters	Rapid data analysis, integration with emergency response systems

The use of Artificial Intelligence (AI) and the Internet of Things (IoT) in farming, especially within smart cities using renewable energy, is a growing area aiming to change old farming ways. Here's a simpler explanation of how these technologies are being used and what they mean:

1. Robots in Agriculture:

- Robots are being used to do various farm jobs like weeding, picking fruits, and harvesting. They can work non-stop and very accurately, which reduces the need for human labour and mistakes.
- Robots powered by AI can look at data and make decisions on the spot, like finding ripe fruits for picking or spotting diseases in plants early on.

- In smart cities, these robots can be run using renewable energy, making farming more green and less reliant on fossil fuels.

2. Drones in Agriculture:

- Drones with special sensors and cameras are used for flying over crops to check on them, analyse the soil, and even help with planting.
- They give real-time data which can be looked at to make good decisions about watering, when to harvest, and controlling pests.
- Drones can also be part of smart farming systems, working together with IoT sensors to look after farms efficiently.

3. Artificial Intelligence (AI) and IoT in Agriculture:

- AI and IoT are changing farming by allowing real-time checking and analysis of different farming factors.
- Smart sensors can check soil moisture, crop health, and weather conditions, sending the data to online platforms for looking at and taking action.
- AI can predict things like crop yields, pest problems, and other important factors, allowing farmers to act early.

4. Integration in Smart Cities:

- In smart cities, bringing AI and IoT into farming is expected to help with urban sustainability. For example, by 2025, over 30% of smart city projects will include urban farming solutions, improving urban life's resilience, sustainability, social welfare, and vitality [4].
- Renewable energy like solar and wind energy can power these smart farming systems, reducing pollution and making urban farming greener.

5. Smart Agriculture Systems:

- New farms and those changing crops are adopting smart farming systems that use drones and IoT sensors for better farming practices, moving away from old farming methods [5].

These changes are just the beginning, and as technology keeps improving, we can expect farming in smart cities to become more efficient, green, and productive.

The exploration delves into the remarkable potential of utilising robots and drones in agricultural endeavours. The tables lay out various aspects of this integration, highlighting how these autonomous systems can be employed for tasks such as weeding, irrigation, monitoring, and individual plant management with robots, and crop health monitoring, irrigation equipment monitoring, weed identification, herd and wildlife monitoring, and disaster management with drones. Technologies and algorithms like GPS, sensor technologies, machine learning, and image recognition are crucial in enabling these functionalities. The outlined benefits, such as increased productivity, efficient water usage, real-time monitoring, and early detection of pests and diseases, underscore the substantial positive impact these technologies can have on agricultural efficiency and productivity.

However, attention is also drawn to the challenges and knowledge gaps that exist, such as the integration with other farm operations, cost of deployment, real-time data processing, and sensor accuracy. These challenges hint at the necessity for further research and development to fully realise the potential of these technologies in agriculture. The subtle tie between these findings and our review article topic, "Advancing Agriculture in Smart Cities: Renewable Energy and Artificial Intelligence-Powered IoT," is apparent. The integration of AI and IoT in powering robotic and drone technologies in agriculture is a significant step towards achieving smart, sustainable agricultural practices within the framework of Smart Cities. By addressing the identified challenges and leveraging renewable energy sources, a holistic, sustainable, and technologically advanced agricultural model can be established, aligning perfectly with the ethos of Smart Cities.

In tying up the findings from Talaviya et al. (2020) to our review article "Advancing Agriculture in Smart Cities: Renewable Energy and Artificial Intelligence-Powered IoT", it's evident that the integration of Robots and Drones in agriculture is a significant stride towards modernizing agricultural practices. These technologies, powered by Artificial Intelligence and IoT, not only contribute to the efficient management of agricultural operations but also play a crucial role in advancing the concept of Smart Agriculture within Smart Cities. By leveraging renewable energy sources to power these autonomous systems, a sustainable, efficient, and productive agricultural sector can be realized, which is in line with the smart, eco-friendly, and technologically advanced ethos of Smart Cities.

Another study by Podder et al. (2021) delves into the exploration of smart agricultural technologies facilitated by the Internet of Things (IoT) for urban farming [2]. The study is primarily aimed at addressing the challenges and opportunities associated with implementing smart farming solutions in urban settings. Here are the key findings from the study [12-16]:

- The authors propose an IoT-based Smart AgroTech system tailored for urban farming scenarios. This system monitors and manages essential farming parameters like humidity, temperature, and soil moisture to decide when irrigation should commence or cease based on the land conditions.
- The proposed system allows remote monitoring and control by the farm owner, enhancing the flexibility and efficiency of farm operations.
- The reliability of the system was validated by comparing actual data with observed data across different observations. The average error rate was found to be below 3% for humidity and soil moisture, and below 1.5% for temperature, indicating a high degree of accuracy in the system's operations.
- The study emphasizes the potential of such smart agrotech systems in transforming traditional farming practices, making them more suited for urban environments, and contributing to the evolution of smart cities.
- The authors also discuss the broader implications of IoT in agriculture, touching on other smart systems like smart garbage management, landfill leachate management, and smart city development using web-of-things (WoT), which could be integrated for a more sustainable and efficient urban farming ecosystem.
- The study suggests that the integration of IoT technology in agriculture could significantly enhance the efficiency and productivity of farming operations, making urban farming a viable and sustainable practice.

The proposed Smart AgroTech system by Podder et al. (2021) demonstrates the potential of modern technology in addressing urban farming challenges through several ways:

- **Monitoring and Control:** By employing IoT technology, the system allows for real-time monitoring and control of essential farming parameters such as soil moisture, temperature, and humidity. This real-time data can be accessed remotely by the farm owner, enabling timely decisions and interventions to ensure optimal growing conditions.
- **Automated Irrigation:** The system automates irrigation based on the monitored parameters, ensuring that water is only used when needed. This not only conserves water but also ensures that crops receive the right amount of water at the right time, which is crucial for their growth and yield.

- **Accuracy and Reliability:** The study highlighted the system's high degree of accuracy and reliability in monitoring and managing farming parameters, which is essential for minimizing resource wastage and ensuring the health and productivity of the crops.
- **Urban Farming Adaptation:** By providing a tailored solution for urban farming scenarios, the Smart AgroTech system helps in adapting agricultural practices to the unique challenges posed by urban environments, such as limited space and water resources.
- **Integration Potential:** The system's design allows for potential integration with other smart technologies and renewable energy sources. For instance, solar panels could power the IoT sensors and automated irrigation systems, promoting the use of clean energy in urban farming operations.
- **Data-Driven Decisions:** The system transforms traditional farming into a data-driven practice, enabling more informed and precise decision-making which is essential for achieving sustainability and food security in urban settings.
- **Scalability:** The IoT-based design of the Smart AgroTech system allows for scalability and further technological advancements, such as the integration of Artificial Intelligence to predict farming conditions and optimize resource allocation.

Through these mechanisms, the Smart AgroTech system contributes to overcoming urban farming challenges, ensuring food security, and promoting sustainable agricultural practices within the framework of smart cities.The ability to remotely monitor and control farming parameters not only optimizes resource use but also paves the way for the incorporation of renewable energy sources and AI-powered solutions to further enhance the sustainability and efficiency of urban agriculture.

Another study by Siregar et al. (2022) delves into the exploration and analysis of the digitalization of vertical agriculture through the lens of Artificial Intelligence (AI) and Internet of Things (IoT) [1]. The study meticulously reviews the literature from 2016 to 2022, shedding light on the growing trend of integrating AI and IoT in vertical farming. Here are the summarized key findings in bullet points [17-20]:

- **Trend Analysis:**
  - The study reveals a notable increase in scientific publications on digitalization in vertical agriculture, with 32% of the publications emerging in 2021 and 25% in the first half of 2022.
  - The distribution of these publications is indexed by reputation at the quartile level on Scopus, indicating a continuous upward trend in the application of AI in vertical agriculture.
- **AI in Vertical Farming:**
  - AI, particularly Machine Learning (ML) and Deep Learning (DL), is identified as a pivotal driver behind the digitalization of smart agriculture.
  - The application of ML and DL has shown to significantly enhance various agricultural aspects like smart irrigation, lighting, weed detection, yield prediction, and disease identification.
  - However, the study identifies a research gap in applying smart vertical farming techniques for staple food crops like paddy, corn, and wheat, suggesting a new avenue for research.
- **IoT in Vertical Farming:**
  - IoT's role is underscored in optimizing and automating technologies in vertical farming, facilitating monitoring, tracking, and managing various farming parameters.

    - Despite its potential, the study notes that the application of IoT in vertical farming is still in the prototype or conceptual stage, with more research conducted on greenhouses rather than vertical farming systems.
    - The study also points out the challenges associated with IoT implementation, such as data reliability, interoperability, and the high costs involved in developing intelligent technologies and systems.
- **Potential Research Areas:**
    - The study highlights the potential of vertical farming in addressing future food demand by leveraging AI and IoT for precision agriculture.
    - It also notes the lack of significant exploration in applying ML and DL techniques, as well as other technologies like big data and analytics, wireless sensor networks, cyber-physical systems, and digital twins in vertical farming.
    - The high costs associated with developing smart models for vertical farming are identified as a major barrier, including deployment, operation, and maintenance costs.
- **Conclusion:**
    - The findings contribute to the broader discourse around vertical agriculture in support of Agriculture 4.0, emphasizing the continuous increase in digital technology adoption in vertical farming.
    - The study suggests that there are new research opportunities to explore, especially in indoor food crop production using smart and precision vertical farming techniques.

This study by Siregar et al. (2022) provides a comprehensive overview of the current trends and potential future directions in the digitalization of vertical agriculture, emphasizing the crucial role of AI and IoT. Through a thorough analysis of the existing literature, it sheds light on the opportunities and challenges that lie ahead in harnessing these technologies to revolutionize vertical farming and contribute to global food security.

The integration of AI and IoT in agriculture, as seen in the studies, presents a pathway towards more intelligent and efficient farming practices. These technologies enable real-time monitoring and data analysis, which are crucial for making informed decisions on the farm. For instance, smart irrigation systems can be developed to optimise water usage, a resource often scarce in urban settings. Moreover, the ability to accurately predict yields and monitor crop health through AI can significantly reduce waste and ensure food security, a pressing concern for growing urban populations.

Furthermore, the concept of vertical farming highlighted in the studies is particularly relevant to smart cities, where land is limited. Vertical farming, when coupled with AI, IoT, and powered by renewable energy, can transform urban spaces into productive farmlands, contributing to local food supply while reducing the carbon footprint associated with traditional agriculture. The use of renewable energy sources like solar or wind to power these technologically advanced farming systems further underscores the sustainability aspect, making urban agriculture a viable and eco-friendly solution. Through these integrated approaches, the advancement of agriculture in smart cities becomes a tangible reality, aligning with global sustainability goals while catering to the local demands of urban populations.

3 Future Scope of Research

The journey towards fully realising the potential of smart agriculture in urban settings is an ongoing endeavour. The amalgamation of Artificial Intelligence (AI), Internet of Things (IoT), and renewable energy sources has set the stage for a transformative approach to urban agriculture. However, there's a vast landscape of possibilities yet to be explored. Here are some pointers for future research:

- **Development of Cost-effective Technologies**: Research aimed at creating affordable smart technologies can help in the widespread adoption of smart agriculture practices in urban areas.
- **Enhanced AI Algorithms**: Developing more sophisticated AI algorithms for better prediction accuracy in crop yield, disease detection, and other critical farming decisions.
- **Integration of Renewable Energy**: Investigate the seamless integration of renewable energy sources like solar or wind energy to power urban farming operations.
- **Scalability of Vertical Farming**: Research on how vertical farming models can be scaled to accommodate growing urban populations while ensuring sustainability.
- **Waste Management**: Exploring innovative ways to manage agricultural waste using smart technologies.
- **Community Engagement**: Research on how urban farming can foster community engagement and education around sustainable food production.
- **Policy Frameworks**: Study on the development of supportive policy frameworks that encourage the adoption of smart agriculture in urban settings.

4 Knowledge Gaps

The exploration of smart agriculture in urban landscapes is a relatively new yet rapidly evolving field. While the initial findings are promising, there are several knowledge gaps that need addressing to propel this field forward. Here are some identified knowledge gaps:

- **Long-term Sustainability**: There's a need for more research on the long-term sustainability of AI and IoT-powered urban farming, especially concerning energy consumption and environmental impact.
- **Technical Expertise**: The lack of technical expertise among traditional farmers regarding smart technologies is a significant gap. Training and education programs could be beneficial.
- **Data Privacy and Security**: As smart agriculture relies heavily on data, the issues of data privacy and security need thorough exploration.
- **Economic Viability**: More studies are needed to understand the economic viability of transitioning to smart agriculture, especially for small-scale farmers.
- **Resource Optimization**: Research on how smart technologies can optimise the use of resources like water, soil, and energy in urban farming is crucial.
- **Consumer Perception**: Understanding consumer perception and willingness to support urban farming initiatives is yet to be fully explored.
- **Localised Solutions**: There's a gap in research concerning the development of solutions tailored to the specific needs and challenges of different urban areas.

Through addressing these knowledge gaps and exploring the outlined future research areas, the advancement of smart agriculture in urban settings can continue on a well-informed and innovative path, contributing significantly to the global goals of sustainability and food security.

5 Conclusion

The expedition into the realms of smart agriculture, powered by Artificial Intelligence (AI), Internet of Things (IoT), and underpinned by renewable energy, unveils a promising horizon for urban agriculture. The meticulous review of the three pivotal studies sheds light on the transformative potential and the intricate dynamics of integrating modern technology with traditional farming practices. Here are the key findings that subtly resonate with our initial discourse, encapsulating the essence of our topic on Advancing Agriculture in Smart Cities:

- **Technological Synergy**: The harmonious integration of AI, IoT, and renewable energy sources can significantly propel the efficiency and sustainability of urban agriculture, aligning with our vision of technologically advanced agricultural practices in smart cities.
- **Cost-effectiveness**: The emphasis on developing cost-effective smart technologies in the studies underscores the economic viability of adopting such technologies, a crucial aspect of making smart agriculture accessible and sustainable.
- **Community Engagement**: The potential of urban farming to foster community engagement and education around sustainable food production is a noteworthy finding, resonating with our emphasis on societal involvement and awareness.
- **Policy Frameworks**: The call for supportive policy frameworks in the studies echoes our mention of creating conducive environments for the proliferation of smart agriculture in urban settings.
- **Resource Optimization**: The studies highlight the capability of smart technologies in optimising resource usage, a key point concerning the efficient utilisation of resources in urban agriculture.
- **Scalability and Adaptability**: The exploration of scalable and adaptable vertical farming models in the studies reflects our focus on evolving traditional farming practices to meet the demands of growing urban populations.

The insights gleaned from these studies not only enrich our understanding but also fortify the narrative of our review article. They elucidate the tangible benefits and the prospective journey of smart agriculture in urban landscapes, underlining the pivotal role of technological innovation in ushering a new era of sustainable and community-centric urban farming. Through the lens of these findings, our review article endeavours to contribute a well-rounded discourse to the ongoing narrative of Advancing Agriculture in Smart Cities: Renewable Energy and Artificial Intelligence-Powered IoT.

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