

HEALTH AND HEALTHCARE SYSTEMS

Avoiding Food Crises via the Internet of Things

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Abstract

The purpose of this report is to examine the challenges farmers encounter in growing nutritious crops, such as water scarcity, soil degradation, and chemical reliance. It will also propose alternative farming techniques integrating Internet of Things technology to enhance food production and resolve the food crisis accessibility via precision agriculture.

6 August 2023

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INTRODUCTION

This report focuses on enhancing food quality and quantity production via integrating Internet of Things (IoT) technologies in agricultural fields. Farming involves repetitive tasks that need to be performed daily to maximize yield and detect harmful insects or weeds that could destroy the crop. Therefore, IoT is a cutting-edge solution that can monitor the crops in minute detail to provide optimal growing conditions and eliminate insects or weeds that could affect the crop negatively.

The problem is that conventional agriculture techniques cannot fulfill the global demand for food. This causes a lack of access to a healthy diet, leading to malnutrition and health issues. Additionally, water is being wasted numerously in farming, which is affecting both the crop quality and the nutrients inside the soil. Accordingly, the purpose of this report is to examine the challenges farmers encounter in growing nutritious crops, such as water scarcity, soil degradation, and chemical reliance. It will also propose alternative farming techniques by integrating IoT technology to enhance food production and resolve food crises via precision agriculture.

This report focuses on analyzing IoT technology solutions for expanding food production rather than discussing the reasons for its limited implementation in the agricultural industry. In addition, this report highlights the shortcomings of traditional farming methods and how food supplements will not be enough to sustain the growing population if these concerns are not addressed. Therefore, this information is intended for computer engineering students and farm owners interested in knowing the problems of conventional agriculture, and the key IoT technologies automation engineers apply to improve farms' produce.

I. BACKGROUND

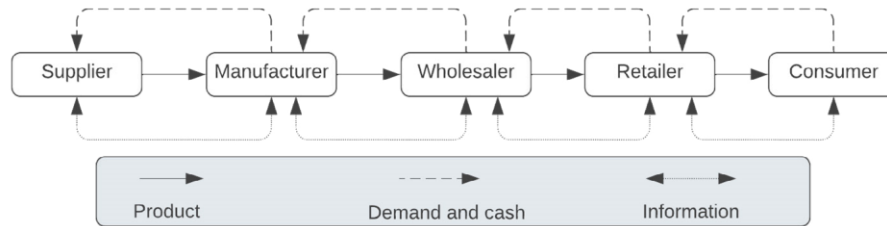
A. The Importance of Accessing Food

Healthy food is abundantly produced worldwide, but access is the primary issue. Local crop cultivation provides sustainable accessibility to fresh and healthy produce, benefiting the community's overall health and chronic disease prevention caused by unhealthy food. This is challenging because not all types of soil are suitable for farming. This leads cities that cannot sustain food production locally to import it from other countries, which leads to many crops arriving rotten or damaged due to the long transportation distances. Mantravadi and Srari (2023, p. 1678) confirm that when it comes to urban food security there is more focus on access to food rather than on its overall availability.

B. The Improvement of the Food Supply Chain

1. *Data acquisition using Internet of Things sensors*

The most fundamental aspect of IoT technologies is the collection of data by sensors. To ensure a constant stream of data, sensors must be connected to the main processor to acquire data from the environment and transmit it to the internet. This data is transferred to suppliers and wholesalers to trace the yield process to ensure its quality during production. Therefore, tracing enables suppliers to identify and address environmental and system issues in real-time without risking supply chain interruptions. As shown in Figure 1, information about fresh food production flows seamlessly from end-to-end, which ensures produce quality.

Figure 1*Food Supply Chain Process*

Note. The above figure shows the processes food supplies go through to reach consumers and how the information is shared via IoT sensors with interested parties. From Mantravadi and Srari (2023, p. 1684).

2. Accommodating crop needs using Internet of Things actuators

Another primary IoT technology is actuators in controlling crop conditions. These devices help regulate the conditions required for crops to grow and produce maximum yields. An actuator utilizes this data to adjust the temperature, humidity, and water level based on the crop requirements, which creates the microclimate needed around each crop to ensure optimal growing conditions. The IoT has revolutionized the utilization of inexpensive hardware, such as sensors and actuators, to enhance irrigation monitoring and climate control systems (Badji et al., 2022, p. 19).

II. PROBLEMS WITH TRADITIONAL FARMING METHODS

A. Water Scarcity

Water availability is the primary concern to farmers as it is essential for growing crops. Water rivers and springs are drying up, and farmers are starting to depend more on artificial sources like desalinated water to irrigate their fields. Subsequently, this is not

cost-effective and often leads poor farmers to use contaminated water to grow. Water irrigation in traditional methods is done by flooding down the field without recycling it, which ensures crops receive enough water to grow and moisturize the soil. However, at the same time, this uses unnecessary amounts of water and affects the plant negatively by reducing oxygen obtainability and thus reducing the crop quality. 40% of the world's food production is done for irrigated agriculture, which uses 70% of the global clean water withdrawals, with only 10% being used efficiently (The World Financial Review, 2021, para. 1). This indicates that water is being wasted enormously, and alternative irrigation methods must be adopted to conserve water usage.

B. Soil Degradation

In traditional agriculture, soil is the primary element for planting crops and sustaining food production. However, as the demand for food grows, the world faces a shortage of fertile soil. Over time, soil loses fertility due to continuous farming in the same soil for decades, ultimately depleting soil nutrients necessary for crop growth. Without sufficient nutrients, the quality and quantity of the yield are diminished, prompting farmers to purchase costly fertilizers to keep the land productive by eliminating nutrient deficiencies. Therefore, the crops' health and size are directly related to the soil's health and the nutrients within it. Soil degradation causes harm to the processes that occur within it, leading to a decrease in soil health, productivity, and biodiversity (Begum, 2021, para. 27). This means that conventional farming methods will be ineffective if soil degradation is allowed to continue.

C. Dependence on Chemical Inputs

The primary objective for farmers is to produce sufficient crop yield to maintain economic viability, which is complicated due to the presence of pests and weeds. Farmers started using harmful chemicals to eliminate unwanted pests and weeds to protect their yield. However, pesticides and weed management chemicals can also negatively impact plant growth by stunting it and causing damage to the roots. The chemicals leave behind residues that can be toxic to both plant growth and human consumers, even after washing. Additionally, using these chemicals leads pests and weeds to develop resistance rendering them less effective and economically unviable. When left unchecked, pests and weeds can seriously impact crops, resulting in productivity reductions of up to 30% while also leading to lower profits and a weaker final product, which is a major concern for consumers (Qureshi, 2022, p. 8). This indicates that chemical dependence should be avoided as it is not an economically viable solution to control pests and weeds.

III. SOLUTIONS FOR IMPROVING CROP YIELD VIA PRECISION AGRICULTURE

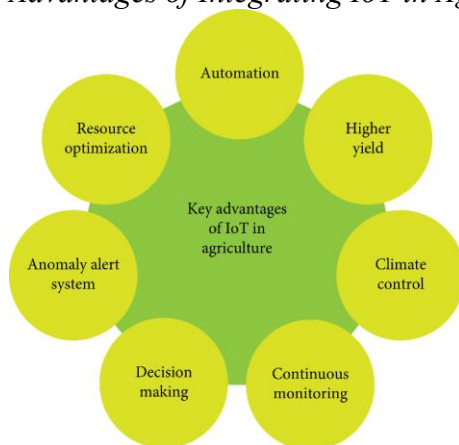
A. Farming Automation

Agricultural automation is a crucial solution implemented by IoT engineers to automate repetitive tasks to reduce farm workers and conserve water. This automation process diminishes the requirement for labor and minimizes human error in cultivating, which ensures consistent crop production. Therefore, repeated tasks such as irrigating, planting, and cultivating are all implemented through IoT actuators without farmers' interventions. Additionally, plants require different climates, which are constructed by

monitoring the microclimate around the plants creating an optimal atmosphere around them by controlling and automating temperatures and humidity levels via IoT actuators. Additionally, the highest usage of clean water resources is gone to farming, which can be changed through smart irrigation systems. Smart irrigation saves a significant amount of water while also being more effective for the crop due to not over-flooding it and allowing oxygen input. Figure 2 demonstrates the advantages of implementing IoT in agriculture, allowing for precision agriculture by automating most processes, such as climate control and resource optimization. This means that farmhands will be reduced, and IoT systems will be adopted in new farmlands.

Figure 2

Advantages of Integrating IoT in Agriculture



Note. The above graph illustrates the benefits of implementing IoT automation in agriculture. From Qureshi et al. (2022, p. 7).

B. Urban Farming

Urban farming is the primary alternative to conventional soil-based agriculture as it eliminates the need for long-distance transportation. Urban agriculture produces food on

small-scale land by cultivating vertically, which in return produces higher crop yield in a smaller footprint. Vertical farming requires less attention as crops are stacked upward, so watering and checking them daily becomes easier. Additionally, producing fresh food near the city eliminates the need for food to travel remote distances to reach supermarkets. Therefore, acquiring food will be healthier and more affordable for the average consumer because it is cheaper to produce on larger scales near the city and will remove the cost of transportation. According to Yuan et al. (2022, p. 2), urban agriculture can assist in alleviating the pressure on rural agriculture and ensuring a stable food supply by implementing innovative methods and technologies. This means that urban farming is the key to sustaining a healthy and cheaper food supply.

C. Hydroponic Farming

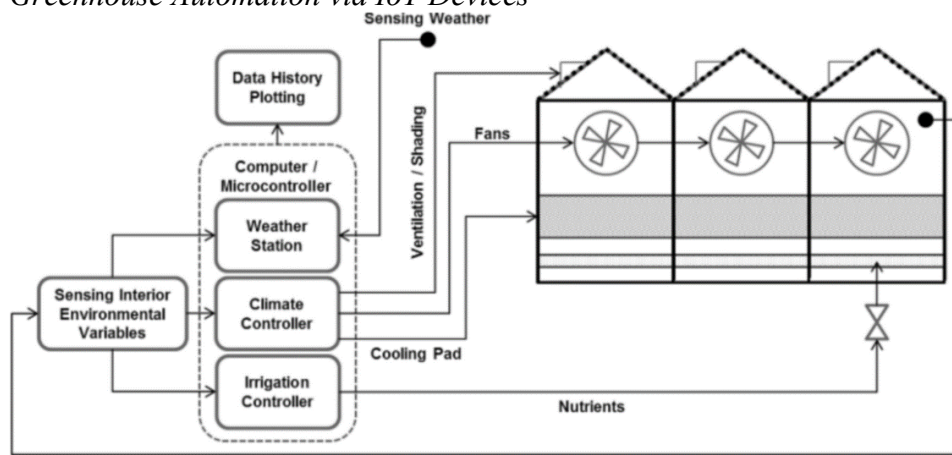
Farming via hydroponic systems is an important solution because it is done without the usage of soil. Soil-based farming requires nutrient care and is becoming less sufficient due to soil degradation. Thus, hydroponic agriculture supplies nutrients the plant needs through a water solution rather than soil. Nutrients are mixed with water, providing precisely what the plant requires, rather than relying on soil, which may or may not have the required nutrients. Additionally, soil-borne diseases are prone to destroy an entire yield in traditional farming. Consequently, hydroponic farms eliminate the need to check with a veterinary due to the absence of waterborne diseases. The hydroponic farming technique effectively prevents crop diseases and promotes faster plant growth (Yuan et al., 2022, p. 3). This indicates that hydroponic agriculture is a healthier cultivating method due to the absence of diseases and chemical inputs used in treating them.

D. Greenhouse Farms

Farming indoors via greenhouses is one major way that can alleviate the world food crisis by increasing food production and eliminating chemical dependence. This method is considered cleaner and more suitable for crops due to providing the specific conditions required for each crop to grow inside greenhouse farms. Therefore, it allows farmers to focus on the crop quality rather than its produce, so chemical inputs are eliminated to ensure enhanced yield. Additionally, water is added depending on the consumption of the plant and then recycled back to the crops to reduce water wastage. This allows the crops to reach their full growing potential without stressing them with unnecessary amounts of water. Figure 3 illustrates how greenhouse farms integrate IoT devices to run the greenhouse automatically to ensure the best growing conditions such as water, climate control, and nutrients required by the plants. This indicates that greenhouse agriculture is great for controlling environmental variables and providing consistent produce around the year.

Figure 3

Greenhouse Automation via IoT Devices



Note. The above figure shows the controlled environmental variables via IoT devices inside an agricultural greenhouse. From Badji et al. (2022, p. 6).

E. Cultivating Crops Indoors

Cultivating in a small indoor space via vertical farming techniques can result in high-quality and fresh produce. Farming hobbyists produce fresh yields in their homes by utilizing an unused area in the backyard or a vacant room. To grow leafy greens, farmers can connect four vertical tubes and use IoT-powered automated climate and irrigation control systems. The system can also be monitored through a phone application, even outside the house. Subsequently, a small space can provide sufficient produce for the farmer with little effort. Moreover, this system enables the farmer to utilize the produce from their farm to ensure that only high-quality dishes are served. Figure 4 demonstrates the confined area required to yield weekly crops of lettuce and broccoli.

Figure 4

Indoor Cultivation Equipment



CONCLUSION

In conclusion, producing enough food is a highly complicated process with many challenges involved. Integrating IoT technology with the farming industry is not applied by most agricultural sites. However, recent farming companies are focusing on implementing IoT technologies with urban farms, and demand for it has enlarged. As a result, many farms have succeeded and proven extremely effective using different farming techniques with integrating IoT automation processes. Moreover, there is a high potential to increase the yield even further when more companies adopt IoT technologies and enhance their abilities to maintain and control farms.

RECOMMENDATIONS

Solving the food production problem will require dedicated work for the farm industry to apply. However, implementing the previously mentioned solutions will be easier with the following recommendations:

1. The Ministry of Environment Water and Agriculture should standardize the technologies and methods used in upcoming farms to increase food production.
2. The Ministry of Irrigation and Water Resources Management should enforce water preservation on farms to eliminate water wastage.
3. The World Food Programme should increase investment in new agricultural industries to increase food production and decrease the cost of its technology.

Word count: 1949

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LIST OF SOURCES FOR PARAPHRASED/QUOTE/TEXT AND FIGURES

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PARAPHRASE, QUOTE OR FIGURE WITHIN REPORT

Location in report: p. 4, I.A. -- Paraphrase

Paraphrase or Figure from report:

Mantravadi and Srai (2023, p. 1678) confirm that when it comes to urban food security there is more focus on access to food rather than on its overall availability.

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1. Introduction

1.1. Urban food security challenges

The world has an urban population of close to 56% (of the total), which is estimated to touch 68% by 2050, according to the United Nations (UN). With the growing urban population, food provisioning is increasingly becoming challenging in many parts of the world. Urban food security is mainly about access to food rather than its actual availability [1] and food provisioning is lately becoming an essential topic of discussion in urban policy worldwide. However, several gaps in the policy prevent an effective policy implementation for urban food security. Wiskerke writes [2]

Urban food security failure is seen as a production failure instead of a distribution, access and affordability failure, constraining interventions in the realm of urban food security.

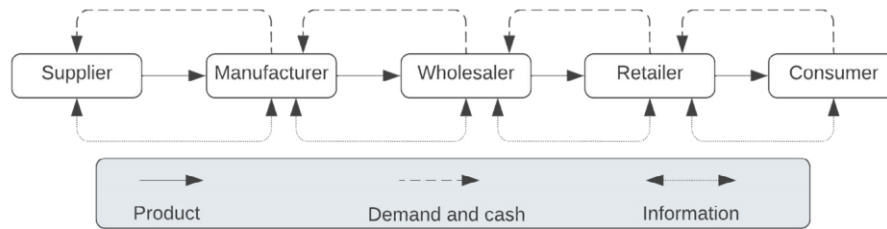
Healthy food access is a critical element of urban food security, and often healthy food (e.g. fresh fruit and vegetable) is also the least processed and most sustainable to the environment. Food manufacturers play an essential role in improving healthy food

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Figure 5*Food Supply Chain Process*

Note. The above figure shows the processes food supplies go through to reach consumers and how the information is shared via IoT sensors with interested parties. From Mantravadi and Srari (2023, p. 1684).

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Soujanya Mantravadi et al. / Procedia Computer Science 217 (2023) 1678–1687

4.2.4.2. *End-to-end supply chain integration*

End-to-end integration in supply chains can refer to inter-organizational integration of the information technology (IT) systems along the supply chain for seamless information exchange in real-time. The term “connected enterprises” [34] was previously used to present the idea of digitally connecting independent supply chain parties that can enable responsiveness and collaborative production planning.

There are several ways to achieve paperless information exchange between food system stakeholders, and traditionally it happens through electronic data interchange, advanced shipping notifications, fax, and emails. However, for real-time information exchange, especially in time-sensitive businesses such as fresh food, it is essential to develop enterprise information systems that can deliver end-to-end solutions in real-time. Inter-organizational collaboration, for example, between manufacturers and wholesalers, can be achieved using next-generation enterprise resource planning (ERP) and manufacturing execution systems (MES). The below figure (see Fig. 4) shows different flows (information, product, and demand) in the supply chain:

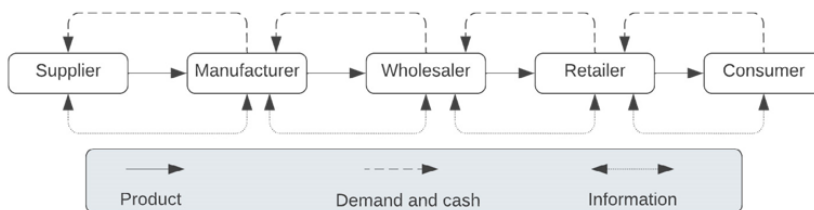


Fig. 4. Supply chain flows [35]

In this regard, MES, an enterprise information system, can provide real-time product-centric data from the factory shop floor. Furthermore, MES can improve supply chain traceability due to its functionalities, such as *genealogy* and *product tracking* throughout a fresh food product's ordering, manufacturing, and delivery process [35]. Therefore, enterprise information systems must be designed and operationalized using modern integration and computing principles for interoperability between supply chain actors. In addition, standardized and flexible information systems can also enable supply network reconfigurability.

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The IoT has revolutionized the utilization of inexpensive hardware, such as sensors and actuators, to enhance irrigation monitoring and climate control systems (Badji et al., 2022, p. 19).

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6. Management of irrigation**Actuators and communication technologies (Internet) to improve irrigation monitoring and control systems.**

The use of IoT to monitor critical parameters in precision irrigation has become popular. The introduction and rapid success of the Internet of Things (IoT) and advanced control strategies are being used to improve irrigation monitoring and control (Bodkhe et al., 2020; Kamienski et al., 2019). Many studies have been conducted on irrigation control systems (Patil and Desai, 2013). devised an intelligent system based on fuzzy logic, which they demonstrated can be efficiently used for water-saving greenhouses. Other researchers have found that a smart irrigation system may save up to 80% water (Boutraa et al., 2011; Darshna et al., 2015; Rawal, 2017). On the other hand, solar energy was used to build smart irrigation power. Nonetheless, the benefits of irrigation modernization include higher water efficiency and production, enhanced irrigation system operation and management, and improved farmer working conditions, although at the expense of increased energy needs and investment amount (Tariuelo et al., 2015).

7. Discussion

According to this literature review, the work done has revealed that research and development projects have sparked much interest in the greenhouse crops sector. From the standpoint of structural hardware, selecting an agricultural greenhouse design to meet the economic conditions of greenhouse growers is always a challenge for the designer. The

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40% of the world's food production is done for irrigated agriculture, which uses 70% of the global clean water withdrawals, with only 10% being used efficiently (The World Financial Review, 2021, para. 1).

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Agriculture relies on many elements to produce food, but the most important of them is water. Irrigated agriculture accounts for 40% of global food production. At the same time, this sector consumes about 70% of the world's water withdrawals, and only 10% is used efficiently. Today, population growth and climate change are making the problem of water waste even more acute.

(5)

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Soil degradation causes harm to the processes that occur within it, leading to a decrease in soil health, productivity, and biodiversity (Begum, 2021, para. 27).

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The cause of soil degradation and how it affects us

Soil is not an inert medium but a living ecosystem that is essential to life. It takes hundreds and thousands of years to form an inch of topsoil, and many more centuries before it is fertile.

While soil degradation is a natural process, it can also be caused by human activity. In the last few decades, soil degradation has been sped up by intensive farming practices like deforestation, overgrazing, intensive cultivation, forest fires and construction work.

These actions disturb soil and leave it vulnerable to wind and water erosion, which damages the complex systems underneath.

Silvia says, 'Several practices associated with intensive agriculture, especially tilling, disrupt soil structure. They accelerate surface runoff and soil erosion, loss of organic matter and fertility and disruption in cycles of water, organic carbon and plant nutrients. These practices also have a major negative impact on soil biodiversity.'

'When soil degrades, the processes that take place within it are damaged. This causes a decline in soil health, biodiversity and productivity, leading to issues at all levels of many ecosystems, and resulting in large environmental consequences such as floods and mass migration.'

(6)

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When left unchecked, pests and weeds can seriously impact crops, resulting in productivity reductions of up to 30% while also leading to lower profits and a weaker final product, which is a major concern for consumers (Qureshi, 2022, p. 8).

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Wireless Communications and Mobile Computing

UAV is a great tool to deal with the variability factor of water stress; sprinkler irrigation can be done using UAV for precise irrigation on the spot [60].

4.3. Pest and Weed Management System. Pest, weeds, and pathogens can affect the crop harshly and may reduce productivity by up to 30% only by weeds [61]. On the other hand, pesticides and herbicides also reduce the profit and degrade the product quality as well which is a big concern for the consumer. IoT and smart systems can assess the disease, pest, and weed in the crop in the early stages and can inform the farmer, also capable of eradicating the pest and pathogens by precise targeting with pesticides and herbicides; smart vehicles [62] can also be used for this purpose.

4.4. Yield Assessment. Yield assessment is the most essential part of smart agriculture. For any type of assessment, data acquisition is the first step. Precise and continuous monitoring for the biotic and abiotic factors is only possible by IoT, WSNs, and UAV imagery. All these devices generate enormous amounts of unstructured data. The acquired data can be utilized for the early prediction of disease [63], crop prediction [64], and harvest planning [65]. Through these applications, farmers can reduce their labor cost and operation cost, can do the error-free assessment for diseases and pests, estimate the revenue and profit, and schedule and plan a more suitable harvesting period that results in less input cost and more profitability in the long run.

[67]. Many researchers have worked to reduce these hurdles and proposed and tested their solutions.

To enhance the UAVs' fly time, ultralightweight WPT systems were proposed [68]. The system is flexible enough to handle air-gap geometrical changes. The system is capable of charging UAVs in midair and extending the flight time to around 7 minutes. Their system can charge drones wirelessly with 10 W. In another work [69], a wireless charging system for UAVs was developed using capacitive power transfer (CPT) technology. This system can charge UASs on wide charging areas. Their system's emitting side is comprised of a circuit, transformer and inductors. The receiving side is comprised of all the small devices using semiconductor elements for a DC-DC converter and charge controlling IC. Their prototype system works on around 12 W and provides more than 50% efficiency.

While considering the magnetic resonant coupling technique due to its efficiency and capability of high power transfer, [70] has proposed and developed a wireless charging system for UAVs used in agriculture fields. In their experiments, they achieved maximum transfer power and efficiency by using FSC coil with 150 coil turns in the transmitter circuit and the MTC comprising 60 coil turns in the receiver UAVs.

Another major hurdle of using UAVs in smart agriculture is path loss while communicating wirelessly due to the surrounding environment, and an accurate path loss model is essential for smart agriculture applications to make sure wireless data communication without unnecessary packet loss among each component of the system. [71] has proposed

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Figure 2

Advantages of Integrating IoT in Agriculture



Note. The above graph illustrates the benefits of implementing IoT automation in agriculture. From Qureshi et al. (2022, p. 7).

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Wireless Communications and Mobile Computing

the variability management practices [50] that could only be done efficiently using the IoT. To wind up the discussion, Figure 3 illustrates the common hurdle in the adoption and implementation of technology in precision agriculture; on the other hand, Figure 4 indicates the key advantages of IoT in precision agriculture (PA). The precision agriculture adoption starting point could be yield monitoring by gathering data to develop spatial and temporal feature



Figure 3: Challenges in technology adoption.

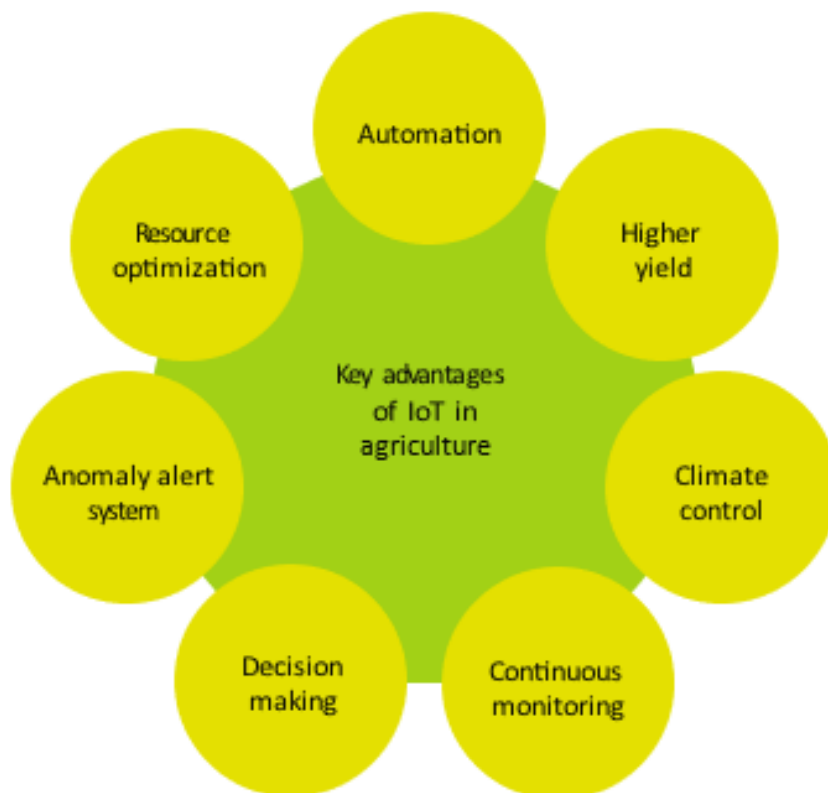


Figure 4: Key advantages of IoT in agriculture.

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According to Yuan et al. (2022, p. 2), urban agriculture can assist in alleviating the pressure on rural agriculture and ensuring a stable food supply by implementing innovative methods and technologies.

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2. Recent status of urban agriculture

UA is considered a common feature of cities in developing countries. Particularly in the Global North, a resurgence of UA in recent years have been associated with socioeconomic benefits including but not limited to food security, social justice, environmental quality, and health, and in some cases “*experimenting with radical alternatives to the capitalist neoliberal organization of urban life*” (Tornaghi, 2014). Furthermore, problems associated with traditional agricultural practices, which can be separated roughly into two categories: those (1) concerning loss of wildlife to expand the arable land and (2) consequences from the intensified land use (Lubowski et al., 2006), had pushed UA as a way to lower the reliance on traditional agriculture. This interest in UA as a sustainable alternative to traditional agriculture, particularly in highly urbanized developed nations, was further highlighted due to UA's role as food source in cities where food supply had been cut due to production and logistic disruption brought by COVID-19 pandemic in 2019. Yet, while having positive prospects, UA also has its own limitations and disadvantages. First and foremost, the concern is the amount of available land in the urban area given the expansion of the cities (FAO, 2011). While the search for a solution for this problem is in progress with new technologies allowing for vertical cultivation of crops, the price of the initial setup remains a relevant concern as it will be inaccessible for the poorer population. Certain special knowledge is required for the large-scale operation of UA installations for commercial gain as well.

By utilizing innovative methods and technologies, UA can alleviate the pressure from rural agriculture and secure food supply within a sustainable framework. With industrial-scale production, rural agriculture is focusing on monocultures which sacrifices diversity of the

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The hydroponic farming technique effectively prevents crop diseases and promotes faster plant growth (Yuan et al., 2022, p. 3).

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2.1.1. Hydroponics

Hydroponics can be considered a form of vertical farming that grows plants in nutrient solutions instead of soil, which can be done with or without the use of inert medium. This is a relatively easy technique that eliminates the possibility of soil-borne disease and stimulates faster growth of the plants (Figure 2). However, while it reduces the amount of water required for irrigation and prevents pests from infecting the plants, it does not rule out the possibility of water-borne diseases, which might spread quicker than soil-borne and destroy the entire yield (Sharma et al., 2018).

Moreover, hydroponics offers farmers a wide variety of other production advantages that should also be noted briefly here. The most

(10)

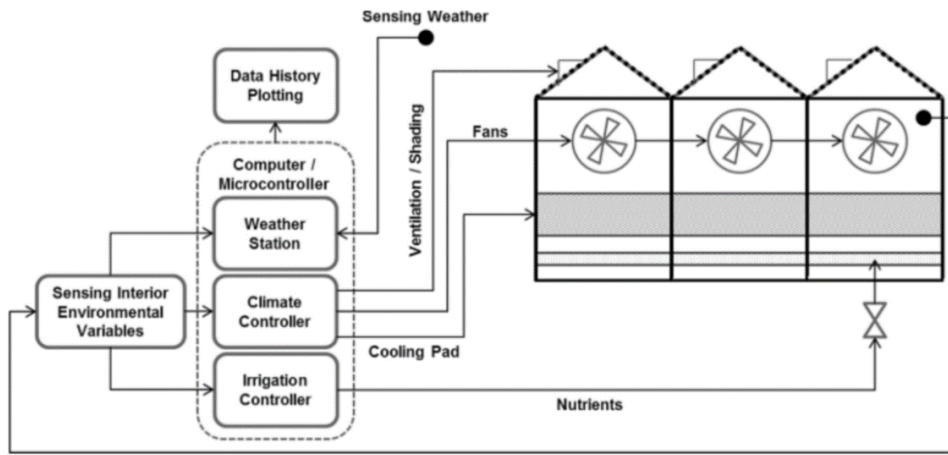
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Figure 6

Greenhouse Automation via IoT Devices



Note. The above figure shows the controlled environmental variables via IoT devices inside an agricultural greenhouse. From Badji et al. (2022, p. 6).

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Image of the used item with grey highlighting:

4. Control and monitoring of greenhouse environment

Greenhouses are extremely complex, nonlinear living systems whose behavior changes over time due to various disturbances, the bulk of which are weather-related. More complicated and intelligent techniques are required to bring together indoor and outside stakeholders, such as the cost of electricity, water, CO₂, and other factors, and make necessary modifications in the greenhouse environment for healthy crop development and hence a profitable operation, as shown in Fig. 7. Smart digital greenhouse environmental control systems are now available. They can integrate every single parameter in a contemporary commercial greenhouse, allowing for smart decision-making for the best possible growing circumstances. Incorporating better tactics with artificial intelligence (AI) algorithms into environmental control systems can result in improved precision and cost savings. Today, remote monitoring and control systems are available 24 h a day, seven days a week, due to artificial intelligence, computer vision, and enhanced sensor integration (Garcia-Lesta et al., 2017). Greenhouses will soon become more adaptable and self-sufficient, making them more common and sustainable.

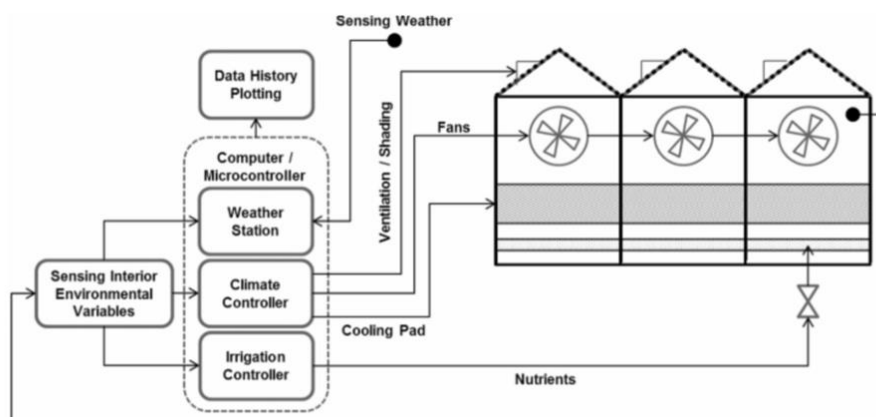


Fig. 7. Diagram of control greenhouse (Ponce et al., 2014).