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The Future of Urban Agriculture: SMART FARMING

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Abstract

In the modern era of machine learning and IoT, traditional farming methods are being transformed, enabling plants to be grown without soil. Techniques like Hydroponics and Aeroponics offer innovative ways to cultivate plants, where IoT and machine learning play key roles in monitoring plant growth, estimating harvest times, and analyzing environmental conditions. This has made farming more efficient and accessible. Another environmentally friendly technique is Aquaponics, which blends aquaculture (fish farming) with Hydroponics (growing plants without soil) to promote a symbiotic relationship between fish and plants. This article explores how data analytics, sensors, and automation are integrated into Hydroponic, Aeroponic, and Aquaponic systems to drive technological advancements and smart farming solutions. With real-time monitoring, these technologies help farmers optimize plant growth and minimize resource waste. The incorporation of IoT devices, machine learning, and AI enhances the systems' ability to adapt to environmental changes. The study demonstrates strong resilience against outliers, achieving high prediction accuracy (94.26%) and lower error rates compared to other models like support vector machines and random forests.

Keywords: Real Time Monitoring, Hydroponic, Aeroponic, Aquaponic, Machine learning, Internet of Things, Smart farming, SVM.

1 Introduction

Combining IoT and Machine Learning (ML) in agriculture can lead to several notable advancements, especially in regards to innovative techniques like Hydroponics and Aeroponics. SVMs can assess plant growth patterns and spacing in Hydroponic, Aeroponic, and Aquaponic systems in order to optimize plant layout for maximum yield. It can make recommendations for the optimal plant spacing configurations to lessen competition for resources and boost overall productivity based on previous data on plant growth rates and geographical distribution. Modern agricultural techniques like Hydroponics, Aeroponics, and Aquaponics provide benefits over traditional soil-based farming. By 2050, it is expected that there will be 9.7 billion people on the planet, making sustainable food production a crucial concern. Innovative solutions are provided by vertical farming systems including Hydroponics, Aquaponics, and Aeroponics, particularly in metropolitan areas

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with limited space and resources. These techniques maximize crop growth and resource efficiency by utilizing cutting-edge technology. These systems are being drastically transformed by the Internet of Things (IoT) and Artificial Intelligence (AI). These technologies allow for more accurate control, real-time monitoring, and data-driven decision-making, which greatly increases productivity and sustainability. The productivity (P) of a farm can be modeled in the context of smart farming utilizing a variety of characteristics impacted by IoT and Machine Learning (ML). The simplified mathematical formula is given by Equation 1.

$$P = f(S, W, N, T, R, ML, IoT) \tag{1}$$

Here, different variables are representative of important factors impacting productivity.

- P represents productivity (yield per unit area)
- S represents soil quality (nutrient levels, pH, etc.)
- W is representative of water availability and usage (irrigation efficiency)
- N represents nutrient management (fertilizer use)
- T represents temperature and climate conditions
- R represents rainfall (or precipitation levels)
- ML machine learning algorithms (predictive models for crop growth, disease detection, etc.)
- IoT devices (sensors, drones, automation systems)

Each of these factors can be influenced by IoT systems and ML models to optimize the overall productivity P.

1.1 Hydroponics

Hydroponics is a way to grow plants in absence of soil, with the use of water fill with nutrients to supply required elements and important minerals directly to the roots of plant. In Hydroponic system, plants are usually developed in a motion less means like vermiculite, perlite, coconut coir, or Rockwoolwhich provides support to the roots whereas allowing them to use the nutrient solution. This method allows plants to be grown without soil by supplying the essential nutrients directly to the roots of the plants through nutrient-rich water solutions. In conventional cultivation, which was based on soil, plants obtain nutrients directly from the soil, but hydroponics eliminates the requirement of soil by providing a controlled environment where nutrients get dissolved straight in water and directly delivered to the plants.

1.2 Aeroponics

A method of growing plants without the need of soil or other traditional growing media is called Aeroponics. As an alternative, it works by suspending the roots of plants in the air and feeding them with nutrients in the form of a fine mist or aerosolized solution. In an Aeroponics system, plants are usually kept in a completely or partially enclosed environment, and a solution fill with nutrients is sprayed directly on the exposed roots at regular intervals. Because of this approach roots have a better contact to oxygen which results in improved health of plants, considerablyquicker crop growth rates and increased yields.Whereas in hydroponics technique, plant roots are soaked in a solution of nutrients and water.

1.3 Aquaponics

Another often used name is "Aquaponics." Beneficial bacteria in Aquaponics transform fish waste from the aquaculture component into nutrients that the hydroponic component's plants may use. Because of their mutuality relationship, plants and fish form a closed-loop system in which the plants clean and filter the fish's water and the fish receive vital nutrients from the waste of the fish. Aquaponics systems can be employed in a range of sizes, from large commercial operations to small

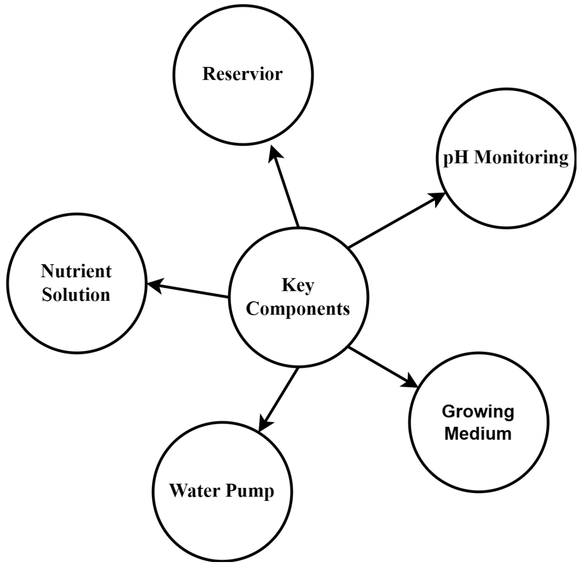

Fig. 1 Key Components of Hydroponic Farming

domestic installations. This innovative farming method has become more popular since it can grow vegetables and fish in a way that is both ecologically friendly and synergistic.

2 Key Components of Hydroponic, Aeroponic and Aquaponic

The Figures 1,2, and 3 show basic key characteristics of these techniques. These key components work together to create an optimal growing environment for plants. All the systems help in promoting rapid growth, high yields, and efficient use of capitals. ML algorithms can be used to assess real-time data from IoT sensors that measure plant growth factors, pH, and nutrient levels. In order to offer plants the right combination of nutrients for optimal growth, ML models can be used to better time and formulate nutrition solutions for the roots. By taking lessons from previous trends and plant responses, this is accomplished.

Fish tanks, plant grow beds, a recirculating water system, and helpful bacteria that transform fish waste into plant nutrients are essential parts of an Aquaponics system. Aquaponics maximizes resource efficiency, lowers waste, uses less water, and integrates fish and plant production to provide a sustainable food production technique. Benefits of Using Hydroponic and Aeroponic system can be summated as follows.

- Due to the system's recirculation of water, hydroponic farming requires a great deal less water than traditional soil-based farming.
- The nutrient levels in the water may be precisely controlled by growers, enabling optimal plant growth.
- Because Hydroponic and Aeroponic systems provide direct access to nutrients, plants in them frequently grow faster than those in soil.
- These systems can be configured vertically or in small spaces, making them suitable for urban farming or regions with limited acreage.

However, some problems of using above system can be identified as under.

- Setting up a hydroponic and Aeroponics system is more expensive than traditional farming.
- Some hydroponic and Aeroponics systems rely on electricity to pump water and nutrients, which can be a concern in areas with unreliable power.

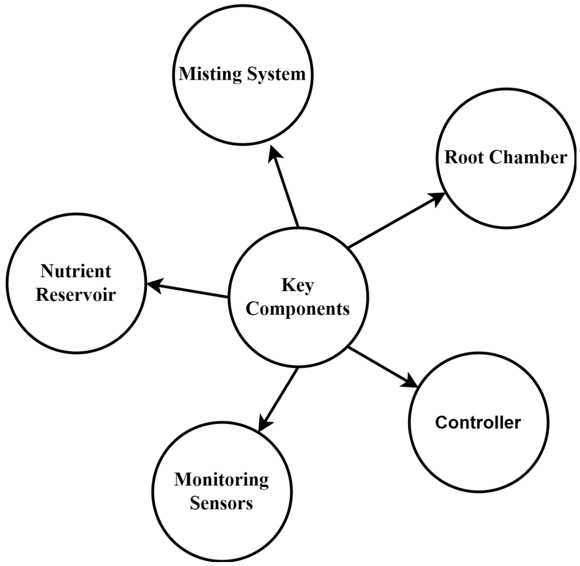

Fig. 2 Key Components of Aeroponic Farming

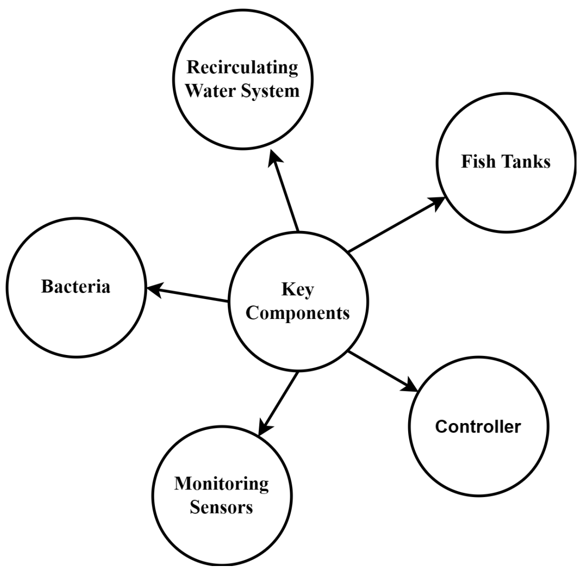

Fig. 3 Key Components of Aquaponic Farming

- Hydroponic and Aeroponics systems require a good understanding of pH levels, nutrient solutions, and system maintenance.

In Table 1, a comparative study among Aeroponics, Hydroponics, and Aquaponics can provide insights into the advantages, challenges, and applications of these different soilless cultivation methods.

3 Preliminary Study

Several studies have looked into how machine learning algorithms and Internet of Things sensors may be used to monitor Advancing Agriculture. Real-time monitoring of crop conditions, soil moisture levels, and weather forecasts is made possible by IoT and ML systems, which empower farmers to

Table 1 Comparison of Aeroponics, Hydroponics, and Aquaponics methods of soilless cultivation

Factors	Aeroponics	Hydroponics	Aquaponics
Basic Concept	Soil-less, mist nutrient system	Soil-less, water nutrient system	Combination of aquaculture and hydroponics
Water Usage	Very low	Moderate	Low (high recycling)
Nutrient Source	Artificial nutrient solutions	Artificial nutrient solutions	Fish waste (organic)
Energy Consumption	High (misting system, lighting)	Moderate (pumps, lighting)	High (pumps, lighting, and fish tanks)
Space Efficiency	High (vertical growing potential)	Moderate Low (requires space for fish tanks)	
Growth Speed	Fastest	Fast	Comparable to hydroponics
Sustainability	Low to moderate	Moderate	High (natural cycle, minimal waste)
Cost	High setup costs	Moderate setup costs	Highest setup costs
Maintenance	High (frequent monitoring)	Moderate (pH, nutrient checks)	High (balance fish and plant needs)

make data-driven decisions that maximize production and reduce input costs. Emergent plants are grown hydroponically—that is, without soil—in a nutrient-rich water solution, typically on inert surfaces. ML and IoT technologies are being used more and more in Hydroponic systems to track environmental parameters including pH, temperature, humidity, and nutrient levels. Research by [1] confirmed the basics of the Hydroponics for predictive analytics in the food production process.The major aim of the research study [1] is to investigate the impact of aeration in mitigating root-related issues. Specifically, this research seeks to compare the efficacy of a Hydroponic system with aeration against an Aeroponic system. The spectrum quality of light is discussed here by [2] for plant growth and development. Some research and thorough study has started to see the impact of Hydroponic types of plantation with the several factors in this research [3]. This work presents an IoT-based Hydroponic monitoring and control system suitable for urban agriculture, discusses the architecture, sensor integration, and remote monitoring capabilities. Early diagnosis of nutrient deficits and optimal fertilizer delivery to plants are made possible by the application of machine learning (ML) algorithms for predictive analytics in hydroponic systems. as demonstrated by research conducted by [4]. Aeroponics is a soilless gardening technique that involves misting plant roots with a nutritious solution on a regular basis. IoT and ML are critical to the automation and optimization of aeroponic systems. In order to enable predictive maintenance and reduce downtime caused by equipment failures, Chen et al. [5] research from 2021 analyzes sensor data gathered from aeroponic systems using a variety of machine learning techniques. Furthermore, [6] developed IoT-enabled Aeroponic systems that made it possible to remotely monitor and modify environmental conditions, enabling precision agriculture operations.

3.1 IOT based automated hydroponic system

On the basis of literature survey, IOT based automated hydroponic system can be divided into five categories.

3.1.1 Without Nutrient and Growth Monitoring

The papers [7–9] discusse an IoT-based automated hydroponic system that monitors factors such as humidity ,temperature, atmospheric pressure, light intensity ,and electrical conductivity for lettuce growth. The research in [10, 11], focuses on plant health in order to preserve ideal growing conditions. Nevertheless, it makes no mention of tracking development and nutrients. Researchers in [9, 12] discuss the use of hydroponics with IoT to solve agricultural issues in India. The paper [13] discusses an automated hydroponics system that improves crop growth and cultivation by delivering water and nutrients efficiently. This paper [14] focuses on monitoring and controlling environmental events such as pH, humidity, water temperature and light intensity. The design of an autonomous pH monitoring and control system for preserving ideal pH values in a hydroponics system is covered in the presented in [15]. However, monitoring of growth and nutrients is not included in any of these articles. An essential task for maximizing the global food supply for proper growth prediction is discussed in [16].

3.1.2 With Nutrient monitoring

In [17–19], an automated hydroponic system with Internet of Things (IoT) technology for fertilizer control and monitoring is proposed. The creation of a hydroponic lettuce growing system is explained that makes use of an Atmega 2560 microprocessor [20, 21]. To maximize lettuce growth, real-time monitoring and regulation of pH, water content, and nutrients are part of it. The creation of an intelligent hydroponic system that can precisely regulate plant nutrition and pH is covered in this study [22]. It also discusses how the pH and nutrient pumps are controlled by the ANFIS algorithm. In order to give plants a constant supply of nutrients, this paper [23] describes an automated hydroponics system that combines nutrient film method and deep water culture. Nevertheless, the paper makes no mention of growth tracking. This work [24] examines in detail the impacts of plant nutrition on hydroponic crop production, as well as the elements that should be included based on the pH of the nutrient solution.

3.1.3 With Nutrient and Growth monitoring

In order to monitor plant development in a hydroponic system, the study [25] addresses the use of three different types of sensors, one of which is a nutrient solution concentration sensor. It does not, however, make specific reference to an automated hydroponic system that monitors growth and nutrients. This research [26, 27] mainly discusses the application of smart sensing-based functional control (SSFC) to lower uncertainty in the interpretation of farm data in agriculture. The focus of this study is on using smart sensors and intelligent decision-making systems to automate farming procedures and improve farming outcomes, rather than on monitoring or analyzing nutrients in crops. This research [1, 28–30] examines the growth monitoring parameters and nutrient distribution monitoring in Aeroponic farming. It covers topics including light intensity monitoring, water and nutrient distribution systems, and control systems to guarantee ideal growing conditions for plants.

3.1.4 With Remote Monitoring

The paper [31, 32] doesn't cover the growth or nutrient monitoring aspects of the automated hydroponic system. The goal of the research is to build an automated hydroponic system for remote monitoring and control utilizing Internet of Things technology. The system under discussion [33, 34] is an Internet of Things (IoT)-based monitoring and control system for hydroponic agriculture. It is composed of sensors that keep an eye on things like nutritional status and a mobile or web application that enables remote access and management. However, it makes no mention of an automated hydroponic system that monitors growth and nutrients. The study [35, 36] emphasized the use of ML-based prototype systems and app-based IoT solutions to provide remote access and monitoring. The study [37, 38] focuses on remotely monitoring crops with an Internet of Things-based system. The system can continually monitor crop-field conditions, including temperature, soil moisture levels, and other vital metrics, by using sensors and Internet of Things technology. The difficulties associated with setting up an Aquaponic system remotely are covered in this paper [39].

3.1.5 Environmental Impact

The technique [40] that we apply in agriculture, there is the need of proper setup and well aware with technology. This paper fully explained the setup of monitoring ways and factors. Machine learning - based system for reducing fresh water waste, this paper helps a lot.

This paper [41] discusses the environmental impact, plant response and implications of the findings for the cultivation of strawberry plants in hydroponic systems under salinity stress conditions.

From these literatures we can easily emphasize that integration of intelligent technologies and precision practices in agriculture has increased the efficiency and resource management of smart agriculture. Current approaches involve leveraging advanced technologies, which include the sensors, automation, Internet of Things (IoT), and data analytics, to make farming more precise, data-driven, and efficient. The use of smart precise agriculture aims to optimize resource management, improve crop yields, and enhance sustainability by precisely monitoring and controlling various factors such as soil conditions, water usage, and crop health. This term underscores the application of cutting-edge technologies to create more informed and efficient farming practices. The key parameters required to calculate the growth rate and making the agriculture system precisely smart are given by Equation 2.

$$GrowthRate = \frac{FinalHarvestWeight – InitialPlantingWeight}{DaystoHarvest} \tag{2}$$

4 The Impact of Technological Advancements on Agriculture

The advancement of technology is transforming the agricultural industry, making it more efficient, sustainable, and productive. Cutting-edge farming methods like Aeroponics, Hydroponics, and Aquaponics are at the forefront of this shift. The following is an analysis of how technology improves these agricultural practices. Aeroponics is an innovative method where plants are grown with their roots suspended in the air and misted with nutrient-rich water. This technique eliminates the need for soil or large quantities of water while maximizing oxygen exposure to the roots, promoting faster plant growth. Hydroponics involves cultivating plants in a water-based, nutrient-rich solution, bypassing the need for soil entirely. The roots are either immersed or suspended in the solution, allowing plants to absorb nutrients directly from the water. Aquaponics merges aquaculture (fish farming) with hydroponics, forming a closed-loop system where fish waste provides organic nutrients for plants, and the plants, in turn, help purify the water for the fish. This interdependent system eliminates the need for synthetic fertilizers. Modern farming techniques like Hydroponics and Aeroponics, enhanced by machine learning (ML) and the Internet of Things (IoT), represent significant advancements for agriculture. Their integration supports precision agriculture, leading to better resource management, higher crop yields, and greater sustainability.

The key advancements driven by ML and IoT in smart farming using Hydroponics and Aeroponics are listed below.

1. ML algorithms process data gathered from IoT sensors, offering real-time insights into environmental factors like humidity, temperature, nutrient levels, and plant health. Automated systems then adjust variables such as nutrient concentration, water flow, and climate conditions to optimize plant growth.
2. ML algorithms, using data from IoT sensors, provide accurate, localized insights on factors like soil moisture, nutrient availability, and environmental conditions.
3. Machine learning algorithms can predict agricultural growth trends, disease outbreaks, and future yield by analyzing both historical and present data.
4. Agricultural methods can be optimized by farmers through intelligent decision-making regarding crop rotations, resource allocation, and pest control techniques.

5. Plant health metrics are continuously monitored by IoT sensors, and ML algorithms can spot early illness or nutrient deficiency symptoms.
6. IoT sensors monitor water usage, nutrient levels, and energy consumption, allowing ML algorithms to identify patterns and recommend optimal resource allocation.This integration minimizes resource wastage, promotes sustainable farming practices, and reduces environmental impact.
7. ML-powered robotics automates tasks such as harvesting, planting, and sorting, improving efficiency and reducing labor requirements. Drones equipped with ML algorithms can survey large agricultural areas, identifying areas that require attention, such as nutrient deficiencies or pest infestations.
8. Farms can be remotely monitored by IoT devices, giving farmers access to real-time data and control systems from any location.
9. After processing data from remote sensing, machine learning (ML) algorithms offer useful insights for prompt problem solving and decision making.
10. ML algorithms analyze diverse datasets to customize growing conditions for different crops, optimizing parameters such as light intensity, temperature, and humidity. The system adapts to changing environmental conditions, ensuring optimal growth and resource utilization.
11. ML-powered analytics optimize overall farm operations, leading to increased efficiency and reduced operational cost.Improved efficiency contributes to the scalability and economic viability of hydroponic and Aeroponics.
12. Machine learning algorithms handle enormous volumes of data, giving farmers useful information for making decisions. By identifying patterns and trends through historical data analysis, our farmers are better equipped to make decisions regarding crop selection, planting schedules, and harvesting techniques.

IoT sensors can monitor the condition of components such as pumps, misters, and filters in the Aeroponic system. Machine learning algorithms are able to examine sensor data and identify trends that point to upcoming equipment malfunctions or inefficiency.

5 Observations

The findings suggest that Hydroponics and Aeroponics represent promising avenues for advancing agriculture through smart farming practices. Several others findings came like customized crop management and environmental impact contributes in energy efficiency and reduces the overall environmental impact of agricultural operations. There are several different types of Hydroponic systems available, such as Deep Water Culture (DWC), Aeroponics, and Nutrient Film Technique (NFT). Each arrangement has advantages and disadvantages of its own, and selecting a specific system depends on several factors, such as the type of plants being produced, the available space, and the grower's tastes and experience. The main findings of the study are summarized here. India is primarily based on agricultural economy and formers put in lot of physical labor to plough their land so the seeds but still are not very sure about the level of output because of the inconsistencies of weather. Using Aeroponic / Hydroponic with Iot and ML will not only allow them to grow crops with no soil but they will be to a great extends able to control the weather conditions leading to a guaranteed crop yield. Iot provides the benefits of remotely controlling the crop environment so the formers need not to be always present near their crop for monitoring this will allow them more freedom to pursue other economic activities. However, one point may be noted that hydroponic and Aeroponic with Iot may not be applicable on certain common crops like wheat, rice etc., this is the limitation of this technique. Future research & development may help us to overcome this situation.

6 Conclusion

Each of these systems offers unique benefits based on the grower's objectives. Aeroponics is highly space-efficient and promotes rapid plant growth, but it comes with increased energy use and maintenance costs. Hydroponics strikes a balance between efficiency and affordability, making it a popular option for many. Aquaponics, though more complex, provides the most sustainable and holistic solution by integrating plant and fish farming in a mutually beneficial system. The decision between these methods depends on factors like available space, budget, environmental impact, and the type of crops or products being grown. The use of technology and the removal of soil constraints create new possibilities to transform traditional agriculture, making it more sustainable, resource-efficient, and better equipped to handle future challenges. However, successfully adopting these techniques requires a deep understanding of their complexities and a careful assessment of the factors affecting their global adoption. Considerations such as upfront investment, operating costs, and potential returns are key to evaluating the long-term viability of these systems. In summary, while Support Vector Machines (SVMs) may not be directly applied within Hydroponic and Aeroponic systems, they can play a valuable role in optimizing various aspects, such as monitoring plant health, adjusting environmental conditions, predictive maintenance, forecasting yields, and optimizing spatial arrangements. SVMs can also identify early signs of equipment failure, helping to prevent system downtime and ensure smooth operations.

Declarations

- The authors received no specific funding for this study.
- The authors declare that they have no conflicts of interest to report regarding the present study.
- No Human subject or animals are involved in the research.
- All authors have mutually consented to participate.
- All the authors have consented the Journal to publish this paper.
- Authors declare that all the data being used in the design and production cum layout of the manuscript is declared in the manuscript.

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