A Comprehensive Overview of Indoor Farming System - Hydroponics

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***Abstract*— The Quality of life has been evolving rapidly through new innovations but at the same time we face new problems. One such problem is that as the population grows, land and water resources are shrinking which is certain to have unknown effects. Hydroponics offers an innovative solution to this as it is a rapidly evolving field that offers numerous benefits in agricultural practices. The stated study explores various hydroponic system types depending upon working mechanisms, analyzing their benefits and challenges. The paper also explores current research findings in hydroponics, focusing on future enhancements of the hydroponic system and the challenges associated with its implementation. Additionally, it investigates the environmental conditions as well as important parameters required for hydroponics cultivation. Through the analysis of various research papers, this study aims to provide a comprehensive understanding of the advancements and obstacles in hydroponics.**

Keywords—Agriculture automation, Hydroponics system.

I. Introduction

World is changing rapidly, bringing resource scarcity, population explosion, climate changes, and urbanization have affected food supply and led to food insecurity and undernourishment. To fight these problems, hydroponics, which is a soilless culture, is presented as an alternative to conventional farming.

Hydroponics is a sustainable model where plants are grown without soil, using nutrient rich water solution to supply essential minerals directly to the plant roots.Hydroponics systems can be designed to use a variety of techniques, including DRFT system which increases air circulation and provides nutrient solution management, Integration of cloud and Iot for data processing and enabling future advancements and M2M for efficient data flow of the system. One of the major benefits of hydroponics is that it allows for precise control over nutrient delivery, resulting in higher nutrient uptake by plants and reducing the need for excessive fertilizer use which promotes faster and healthier plant growth[1].

Within the realm of hydroponics,Deep Water Culture (DWC) systems have gained prominence where plant roots are suspended in a nutrient solution with continuous aeration, allowing for direct access to oxygen and nutrients. It is particularly relevant in urban farming and controlled environment agriculture (CEA) settings, where space is limited, and precise control over growing conditions is essential [2].

The automation of DWC ensures that the plants receive the ideal growing conditions without the need for constant human monitoring and intervention. Additionally, automated DWC systems can be customized to suit the specific needs of different plants, making it possible to grow a wide range of crops within same set of resources with ease. This automation can make DWC hydroponics more efficient, minimizing the risk of crop failure and maximizing overall productivity.

II. Hydroponics: Types and Setups

1) *Deep Water Culture (DWC) System*

Deep water culture is a type of hydroponic system in which plant roots are suspended in a nutrient rich water solution. The roots are typically held in place using net pots, which allow them to remain in contact with the nutrient solution while allowing for adequate oxygenation. The plants are grown in a shallow container or reservoir, and an air pump is used to oxygenate the water and prevent stagnation.

Deep water culture is a simple and effective hydroponic system, making it a popular choice for beginners and small-scale growers. It is also a highly efficient system, as the plants can absorb nutrients directly from the water solution without the need for soil or other growing media. However, deep water culture can be challenging to set up and maintain, as it requires careful monitoring of the nutrient solution's pH levels and oxygenation levels to ensure that the plants are healthy and thriving[3].

2) Nutrient Film Technique (NFT) System

The NFT system is another type of hydroponic cultivation where a thin film of nutrient solution continuously flows over the plant roots, providing them with a constant supply of nutrients and oxygen. In this system, the plants are placed in sloping channels or gutters, and a thin film of nutrient-rich solution is continuously pumped through the channels, allowing the plants to take up the necessary nutrients while also providing oxygen to the roots. The excess nutrient solution is then collected and recirculated back to the reservoir to minimize waste. The NFT system is commonly used for growing crops like lettuce, herbs, strawberries and spinach[4].

3) Drip System

The drip system is one of the most commonly used hydroponic systems. It involves the use of a timer-controlled pump that delivers nutrient-rich water to the plants through a network of tubes and emitters. The solution is dripped onto the roots of the plants at regular intervals, providing a controlled and precise delivery of nutrients. The excess solution is collected and recirculated back to the reservoir, minimizing waste. Drip systems are versatile and can be used for a wide range of crops, including tomatoes, peppers, cucumbers and spinach.The Freight Farms hydroponic organization have also designed to use recirculating drip systems onto the top of 256 crop segment container which utilizes the water in an efficient way, less than 5 gallons per day for around 5000 crops[5].

4) Dynamic Root Floating Technique (DRFT) System

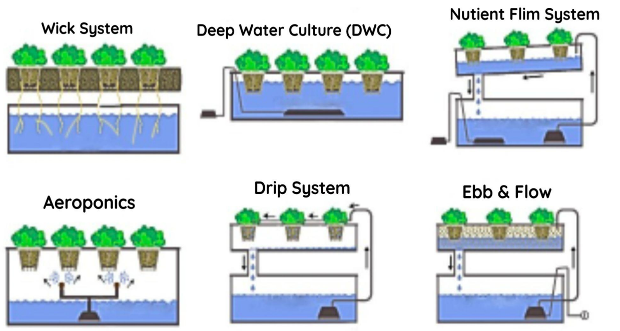
The DRFT system is a type of hydroponic cultivation where nutrient solutions constantly flow through the plant roots at a constant depth in the planting tray. This system ensures continuous nutrient supply to the plants and is implemented in agriculture with the hydroponic DRFT model. In the DRFT system, the plants are placed in a tray with their roots suspended in the nutrient solution. The nutrient solution is continuously circulated through the tray, providing the plants with the necessary nutrients for growth. This system is commonly used for growing leafy greens and herbs. This system can be implemented in hydroponics greenhouses, which are equipped with features such as increased air circulation and nutrient solution management[6].

5. EBB and Flow System

The EBB and Flow system, also known as flood and drain system, involves periodically flooding the plant roots with nutrient solution and then draining it away. This cyclic process ensures proper nutrient uptake by the plants and can be automated using various control technologies. In this system, the plants are placed in trays or pots, and the nutrient solution is pumped into the tray, submerging the roots. After a certain period of time, the excess solution is drained back into the reservoir. This cycle of flooding and draining provides the roots with access to good nutrients and oxygenation while also preventing water logging of the root and promoting healthy growth. The EBB and Flow system is versatile and can be used for growing a wide range of plants such as cucumbers and melons[7]

6) Wick System

The wick system is a passive hydroponic system that uses a wick to transport the nutrient solution from a reservoir to the plants' roots. In the wick system, plants are placed in a growing medium, such as perlite or vermiculite, which act as a wick to draw up the nutrient solution from a reservoir. The wick, usually made of a porous material like cotton or nylon, draws up the nutrient solution through capillary action, ensuring a constant supply of nutrients to the plants. The nutrient solution in the reservoir is usually a mixture of water and hydroponics nutrients, providing the essential elements needed for plant growth. This system is simple and low-cost, making it suitable for small scale hydroponic setups. NASA has set-up sustainable agricultural methods for space missions and has experimented on crops like soybean, wheat, tomatoes and lettuce and has established a life support system in space and analyzed that for a 20-25 square meter of crops grown, could support oxygen for a single person in space[8].



Technique	Medium for nutrient supply	Works well for	Root exposure to nutrients	Pumped Water supply	Water demand	Disease
Wick system	Wick	Small plants, Home grown	Root receives nutrient water through wicks	No	Nominal	Fungal disease and root rot
Deep water Culture	Plants held in netted pots	Compact and scalable	Roots throughout dipped in water nutrient solution	Filled container	Maximum but reusable	Insufficient oxygen content
Nutrient Film Technique	Sloping channels for nutrient water	Domestic and Commercial hydroponics	Partial thin film of exposure to nutrient solution	24 X 7 pumping through a sloped channel	Nominal	Root Rot
Ebb and flow method	Flooded and drained with nutrient water	Small scale and large-scale implementation	Root exposure in bursts	Intermittent supply of water	On and off	Healthy Root development
Drip Irrigation	Drip line via pump & timer	Commercial application;	On and Off exposure to Nutrient solution during the drip	Pipe supply and drip emitter	Nominal	Fungi/Bacteria infection in media bed
Aeroponics	Atomizers are required	Commercial application	Exposure in bursts	Sprinkler with mist nozzles	Minimum	Healthy roots

Table I. Details Pertaining To All The Methods Used In Hydroponics[9]

III. Parameters Of Automations

1. Electrical Conductivity (EC) / Total Dissolved Solids (TDS)

EC/TDS measures the concentration of dissolved salts in the nutrient solution. Monitoring and adjusting EC/TDS levels ensure that plants receive the appropriate amount of nutrients for optimal growth. High EC/TDS levels can lead to nutrient imbalances and toxicity, while low levels can result in nutrient deficiencies. By maintaining the appropriate EC level, nutrient imbalances can be avoided, preventing nutrient deficiencies or toxicities.The EC level of the nutrient solution indicates the concentration of nutrients and needs to be maintained within the recommended range (0.8-1.2 for lettuce and 1.8-1.9 for other plants)[10].

2. pH Level

pH measures the acidity or alkalinity of the nutrient solution. It is a critical parameter that needs to be monitored and controlled in hydroponic systems because it affects nutrient availability and uptake by the plants. Most plants thrive in a slightly acidic to neutral pH range, typically between 5.5 and 6.5. Monitoring the pH level allows for adjustments to be made using pH adjusters such as pH up or pH down solutions to maintain the optimal pH range for plant growth [11].Maintaining the correct pH level is important because if the pH is too high or too low, it can lead to nutrient lockout, where certain nutrients become unavailable to the plants even if they are present in the solution. This can result in stunted growth, nutrient deficiencies, and reduced crop yields. If the pH drops below 6.2, a peristaltic pump is triggered to add acid to increase the pH. Conversely, if the pH rises above 7.5, the pump adds base to decrease the pH.

3. Temperature

Temperature plays a significant role in plant growth and metabolism. It affects nutrient uptake, enzymatic activity, and overall plant health. Different plants have different temperature preferences, but generally, a temperature range of 18-25°C (64-77°F) is suitable for most hydroponic crops. Extreme temperatures can stress the plants, inhibit nutrient uptake, and increase the risk of diseases.[12] Controlling the temperature within this range promotes optimal plant growth and prevents stress or damage caused by extreme temperatures.Temperature influences various physiological processes in plants, including photosynthesis, respiration, and transpiration. If the temperature is too high, it can lead to increased water loss through transpiration, reduced photosynthetic efficiency, and heat stress. Conversely, if the temperature is too low, it can slow down metabolic processes and hinder nutrient uptake.

4. Light Intensity

Light is essential for photosynthesis, the process by which plants convert light energy into chemical energy. In DWC hydroponics, controlling light intensity is crucial to provide plants with the right amount of light for photosynthesis and promote healthy plant growth. Light intensity affects the rate of photosynthesis and influences plant growth and development[13]. Insufficient light can lead to reduced photosynthetic activity, elongated and weak stems, and poor fruit or flower production. On the other hand, excessive light intensity can cause photoinhibition, where the excess light damages the plant's photosynthetic machinery. This information helps farmers adjust artificial lighting or shading to provide the optimal light conditions for different plant species. UV lights are programmed to stay on from 0-12 hours and turned off from 12-24 hours. A relative study on “Brassica Chinensis” plant with Red Blue White (RBW) LEDs without a Far-Red treatment of ratio 16:4:2 and RB LEDs with a Far-Red treatment of ratio 16:4:16 for photosynthesis effect had successfully experimented[14].

5. Humidity

Humidity levels affect transpiration rates and water uptake by plants. Maintaining appropriate humidity levels in DWC hydroponics is important to prevent water stress or moisture-related issues such as wilting or fungal diseases and ensure that plants can efficiently absorb water and nutrients through their roots. Different plants have different humidity preferences, but generally, a humidity range of 50-70% is suitable for most hydroponic crops. During the transition from germination to vegetative phase the RH value is 40-60% and during blossoming phase the RH 40-50%. Low humidity levels can lead to increased transpiration rates, resulting in water stress and wilting. High humidity levels, on the other hand, can create a favorable environment for fungal diseases and hinder transpiration, leading to reduced nutrient uptake and growth. Maintaining the appropriate humidity levels for each plant species ensures optimal water balance and promotes healthy growth[15].

6. CO2 levels

Carbon dioxide (CO_2) is a key component for photosynthesis. Monitoring and controlling CO_2 levels in hydroponics ensures that plants have an adequate supply of CO_2 for efficient photosynthesis and maintaining optimal CO_2 levels can increase the rate of photosynthesis and overall plant growth. Different plants have different CO_2 requirements, but generally, a CO_2 concentration of 1000-1500 ppm (parts per million) is suitable for most hydroponic crops. Insufficient CO_2 levels can limit photosynthetic rates and reduce plant growth. Increasing CO_2 levels can enhance photosynthesis and promote faster growth and higher yields. However, excessively high CO_2 levels can lead to carbon dioxide toxicity and negatively impact plant growth[16].

7. Nutrient solution composition

The nutrient solution in hydroponics provides essential minerals and nutrients for plant growth. The composition of the nutrient solution needs to be carefully monitored and adjusted to meet the specific nutrient requirements of the plants being grown. This includes providing the right balance of macronutrients (such as nitrogen, phosphorus, and potassium) and micronutrients (such as iron, zinc, and manganese). The concentration and balance of these nutrients need to be carefully monitored and adjusted to meet the specific needs of different plant species and growth stages. Regular monitoring of nutrient levels, such as through electrical conductivity (EC) measurements, helps ensure that the nutrient solution is within the optimal range. Adjustments can be made by adding or diluting nutrient solutions to maintain the desired nutrient concentrations. This ensures that plants have access to the right nutrients at the right time, promoting healthy growth and maximizing productivity[17].

8. Substrate characteristics

The choice and quality of the substrate used in DWC systems is typically an inert material like expanded clay pellets or rockwool cubes that impact root development and nutrient absorption. The substrate should have appropriate water-holding capacity to ensure that the roots have access to water and nutrients. At the same time, it should also have good aeration properties to prevent waterlogging and promote oxygen availability to the roots. Cocopeat is a commonly used substrate in hydroponics due to its stability, lightweight nature, and ability to exchange cations. Other innovative substrates, such as biochar and hydrochar derived from organic waste, have also been explored for their potential in enhancing plant growth[18].

9. Dissolved oxygen levels

Oxygen is essential for root respiration and nutrient uptake. In DWC hydroponics, monitoring and maintaining adequate dissolved oxygen levels in the nutrient solution is crucial for preventing root diseases caused by anaerobic conditions and promoting healthy plant growth. The roots need access to oxygen to carry out essential metabolic processes. Oxygen levels can be affected by factors such as water temperature, nutrient solution circulation, and aeration. Adjustments can be made by increasing aeration or adjusting the nutrient solution circulation to maintain optimal dissolved oxygen levels. Insufficient dissolved oxygen levels can lead to root suffocation and hinder nutrient uptake, resulting in poor plant growth and reduced yields. On the other hand, excessive dissolved oxygen levels can cause oxygen toxicity and damage the roots. The recommended dissolved oxygen levels in DWC hydroponics systems are typically between 5-8 mg/L[19].

IV. Automation Technologies

1. Sensor Technology

Sensors play a crucial role in automation systems by continuously monitoring the conditions of various parameters such as light intensity, temperature, humidity, water level, pH levels, TDS and nutrient concentration in the hydroponic system.These sensors provide accurate and real-time data, allowing farmers to make informed decisions and adjust the system accordingly. For example, Light sensors measure the intensity of light, allowing for adjustments to be made to provide the optimal amount of light for photosynthesis. TDS sensors measure the nutrient concentration at the top level and automate the watering process if it falls below a predefined threshold.

2. Actuator Technology

Actuators are devices that are used to control and adjust environmental conditions in the hydroponic system and convert electrical signals into physical actions. In hydroponic systems, actuators are used to automate tasks such as adjusting pH levels, controlling nutrient delivery, pumps, valves, fans and providing aeration.For example, solenoid valves control the flow of nutrient solution, allowing for precise control over nutrient delivery. Peristaltic pumps adjust the pH level by adding pH up or pH down solutions. These actuators are controlled by the microcontroller based on the sensor data, ensuring that the parameters are maintained within the desired range[20].

3. Control Systems

Control systems are the backbone of automation in hydroponics that are used to automate the monitoring and adjustment of environmental parameters. These systems receive data from sensors and use algorithms & logic to analyze the data and make decisions on adjusting the parameters. They activate the appropriate actuators to maintain optimal conditions for plant growth. Fuzzy logic control, for example, is a popular approach that uses linguistic rules and fuzzy sets to make decisions based on imprecise or uncertain data. Control systems can be implemented using microcontrollers, programmable logic controllers (PLCs), or computer-based software[21].

4. Integration of IoT

The hydroponics system in this study was integrated with Internet of Things (IoT) technology, it is a network of interconnected devices that can communicate and exchange data with each other and it is a technology that used to connect sensors, actuators, and control systems, allowing for real-time monitoring and control of various parameters such as EC, pH, temperature, and nutrient concentration. IoT enables remote access and control of hydroponic systems, in this case the ESP 32 microcontroller served as the central hub for collecting data from various sensors and transmitting it to the IoT-enabled cloud it providing farmers with the ability to monitor and adjust the growing conditions from anywhere using a Web and Mobile Applications[22].

5. Data Analysis and Decision-Making

Automation technologies in hydroponics generate a vast amount of data from sensors and other sources. Data analysis techniques, such as machine learning and data mining, can be used to extract valuable insights from this data. By analyzing this data and patterns, farmers can gain insights into the performance of the system, identify trends, and automation systems can make informed decisions and adjustments to optimize plant growth and resource utilization. Data analysis can help optimize resource usage, identify potential issues or anomalies, and improve overall system efficiency and it also enables predictive modeling and decision-making in hydroponics[23].

V. ENVIRONMENTAL CONDITIONS FOR HYDROPONICS

Importance of a suitable growth environment. Agriculture is an industry heavily dependent upon the environment. Hydroponics being a part of its subset is more so. But environmental considerations change as compared to traditional ones. But it's more similar to greenhouse farming. We will see all the major considerations as per hydroponics plantation. A lot of this parameter can be automated and remote controlled but it will add to complexity. Following are some of these considerations.

1) Ambient conditions based on spatial and temporal dimensions

In any plantation, the ambient conditions are not fully uniform. The spatial, vertical, and temporal variability of ambient environments is important for optimum cultivation. A Korean study conducted by Chungnam National University discovered that overall temperature increased from 12:00 to 14:00 and then increased, while RH increased continuously during the experiments. When one of the side windows was open, the difference between the maximum and minimum temperature and RH readings was larger than when both windows were closed. The maximum and minimum measurements were also at different locations and heights, and PPF and CO2 concentrations varied with time, height, and location. The highest PPF values were seen at a height of 3 meters, close to the light source and CO2[24].

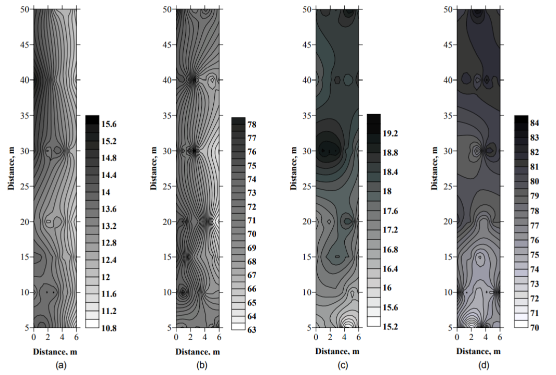
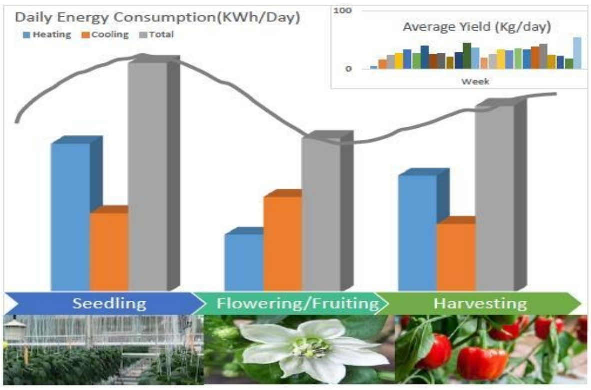


Figure 6. Spatial distribution of air temperature and humidity at a 0.5-m height in greenhouse 1 : (a) air temperature and (b) RH with the right side window open at 12:00, and (c) air temperature and (d) RH with the both windows closed at 14:00.

2) Time and season-based variations

This generates variance in energy use in plantations since certain parameters such as temperature and humidity must be maintained, according to a government-funded study in Australia. Total power consumption reported throughout the crop cycle for heating (gas hot water system) and cooling (pad and fan) was 12,503 and 5183 kWh, respectively; thus, heating consumed the majority of total energy requirement over the 8-month growing period (early spring to late autumn) in plantation faculty. Regressions of daily energy consumption within each season, indicating that energy consumption was 14.62 kWh per 1 °C heating and 2.23 kWh per 1 °C cooling[25].



3) Controlled and uncontrolled parameter fluctuations

Temperature, humidity, soil moisture, light intensity and CO2 are some of the major controlled parameters in most studies but as seen they do not stay uniform over the plantation. It can be hypothesized that this level of non-uniformity might cause considerable damage to crop growth. In this Korean government funded study several variants of control systems, within the framework of the multiple sensor nodes system, have been proposed to provide a more thermally stable cultivating environment, and the experimental verification is carried out for different scales. A more precise sensing or monitoring system with higher spatial resolution is introduced with the multiple sensor nodes system based on a wireless sensor network but the behavior and characteristics for other main control variables, such as a humidity and CO2 concentration, is to be investigated[26].

4) Conditions based on location

This is the most complex issue whenever a plantation needs to be set-up. Prior data of the location is always useful but actual cost and energy requirements vary as per different climate and environmental factors. Although regression models can be used if available data is available to map to cost and energy requirement, and how ambient parameters will be affected. In such cases government statistics should be prepared[27].

VI. Challenges in Automation

1) Power Optimization

When it comes to power optimization, there are two scales to consider. On a large and small scale. On a larger scale, it has to do with precision hardware control and optimized power consumption strategies[28].On a large scale, using sustainable energy is desired, while solar power and other forms of sustainable energy have been developed. However, the amount of power produced varies, and in the event of erratic weather, it is impossible to receive sufficient power. Therefore, it is necessary to store the generated energy in a battery , however this itself leads to technical issues with energy storage such as battery degradation and limited capacity. Furthermore, small-scale power optimization involves increasing the effectiveness of certain systems and devices to reduce power consumption. This can include implementing energy-saving features, optimizing algorithms, and using power management techniques[29].

In both large and small scale power optimization, the goal is to minimize power consumption, reduce carbon footprint, and promote sustainability. This is important not only for cost savings but also for environmental reasons, as excessive power usage contributes to greenhouse gas emissions and climate change.

2) Hardware Selection

In hydroponics , a lot of electronics hardware needs to handle various constraints like power, i/o specification, and technical expertise required to handle them. However, that is not the only thing. We also need to consider enclosed and other planting tools procurements as lots of locations do have metal resources for manufacturing, while plastics ones do not.

3) Automation Challenges

Challenges like sensor reliability, system complexity are all some technical constraints that must be taken into consideration while building any embedded system. Data security, and human Interventions are another aspect of design as Not all security solutions give us the same level of security against all types of threats, rather every solution is fine-tuned for a particular type of threat or problem and aims to solve that. Also, those solutions that have a narrow scope tend to do better within that scope. Depending on the proposed hydroponics we need to make respective changes[30].

4) Reducing Water Use And Discharge To The Environment

Although designing agricultural production systems for zero discharge to the environment (zero agricultural discharge system) has the potential to protect groundwater, make water permits easier to obtain, and contribute to the long-term sustainability of agricultural enterprises, no long-term studies have been conducted to provide growers with firm guidelines for system management[31].

5) Chemical Management Of Nutrient Availability In The Hydroponic Solution

Solution chemistry is critical when working with hydroponic cultures to maintain proper nutrient concentrations for plant uptake. When making nutritional solutions with salts or concentrated liquid stocks, in particular, certain chemical equilibria, especially solubilization/precipitation equilibrium, must be taken into consideration.[32].

VII. Future Enhancements of the Hydroponic System

1) Hydroponics For Space[33]

Hydroponics for space is a heavily researched field that focuses on its applications in water purification, oxygen and carbon dioxide balance in space stations, and astronaut nourishment[34]. In-depth study is being done in this area since it is essential for long-term space initiatives and the safety of the crew on manned space flights. LED illumination is being investigated for the purpose of growing plants in diverse color spectrums with less heat, specifically for hydroponics on Mars. For the health and sustenance of astronauts in space, fresh food from hydroponic growing is quite beneficial[35].

2) Overcome Adverse Effects Of Brackish Water

The use of brackish water in agriculture may cause the soil's salt content to rise, which may have a detrimental effect on plant output. However, adopting hydroponic cultivation techniques can help to mitigate this issue. Hydroponics is a process that includes growing plants in a nutrient-rich water solution rather than soil. Even with brackish water, this approach promotes superior plant growth and development[36].

3) Improving The Operation Of Hydroponic Installations

Several requirements must be taken into consideration when developing the upgraded hydroponic systems. The first requirement was that they be universal, i.e., capable of supporting a variety of plant species. The second goal of the installations was to maximize the crops' access to water, nutrients, light, and air. Thirdly, they concentrated on making the most of the available space by giving each plant more room while still preserving the health of their stems and shoots[37].

4) Monitoring And Automation With Iot[38]

Automation is the main factor that makes this kind of development possible by spotting inappropriate reactions and fixing them for improved results[39]. Hydroponics has the benefit of allowing for monitoring and automation, which allows for remote management and control of the growing environment. Growers may easily monitor and modify the settings of their hydroponic systems from anywhere at any time by utilizing smartphones or PCs. The success and effectiveness of hydroponic operations are increased as a result of the quick response that can be given to any modifications or problems due to this remote accessibility.

5) AI Introduction - Data Analytics

Growers can benefit from monitoring's insightful data analytics[40]. Growers can improve plant growth and resource use by identifying trends, patterns, and correlations in the data they have collected. The hydroponic system can be continuously improved and tuned thanks to this data-driven approach, which ultimately results in increased crop yields and better resource management[41].

6) Ml And Other AI Techniques

Real-time monitoring and control are made possible in hydroponics through machine learning. A hydroponic system's environmental parameters can be continuously monitored and adjusted using ML algorithms. For instance, the ML algorithm can automatically alter the nutrient solution to ensure optimal plant nutrition if the nutrient levels are found to be poor. This level of automation guarantees predictable and optimal plant growth while also saving growers time and effort.. Machine learning algorithms make the decision based on the predefined data set values. Here feature selection is very important and can be done using regulation algorithms like lasso and ridge[42].

7) Image Analysis

Research is being done on the preprocessing of image data. Common techniques for preprocessing include thresholding, grayscale conversion, and image cropping. These methods are intended to get the images ready for examination and later use in machine learning algorithms. For the agriculture industry, creating image data can provide useful information[43].

VIII. Conclusion

As the world grapples with global challenges, the synthesis of hydroponics and electronics and other deep technologies presents a compelling avenue for innovation in modern agriculture. Parameters that linearly affect plant growth such as Electrical Conductivity (EC), pH levels, temperature, light intensity, humidity, CO2 levels, nutrient solution composition, substrate characteristics, and dissolved oxygen levels are investigated. . The paper reviews sensor technology, actuator technology, control systems, Internet of Things (IoT) integration, and data analysis techniques as they relate to automating hydroponic setups. IoT integration, in particular, is explored as a means of enabling real-time monitoring, remote access, and data-driven decision-making in hydroponic systems. The potential for applying electronic expertise in optimizing and advancing these technologies for sustainable agriculture is seen as a key theme.

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