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A Comprehensive Overview of Indoor Farming System - Hydroponics

Varad Chaskar
varad_chaskar@moderncoe.edu.in

Janhavi Bhor
janhavi_bhor@moderncoe.edu.in

Sahaj S. Chaudhari
sahaj_chaudhari@moderncoe.edu.in

Ramgopal Sahu
ramgopal.sahu@moderncoe.edu.in

Student[123] and Assistant Professor[4] of ENTC

***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 attempts to offer a thorough grasp 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 plant are grown without soil, using nutrient film techniques or equivalent to supply essential minerals directly to the plant roots.Hydroponics systems can be designed to use a variety of techniques, including DRFT system which increased air circulation and nutrient solution management, Integration of cloud and Iot for data processing and enabling for future advancements and M2M for efficient data flow of the system. One of the main advantages of hydroponics is that it provides accurate control over the distribution of nutrients, resulting in higher nutrient uptake by plants and reducing the need for excessive fertilizer use that promote faster and healthier plant growth[1].

Within the realm of hydroponics,Deep Water Culture (DWC) systems have gained prominence where a nutrient solution with constant aeration suspends plant roots, 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 monitoring and intervention from the grower. Additionally, automated DWC systems can be altered to meet the unique requirements of various plants, making it possible to grow a wide range of crops 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

In a hydroponic system known as deep water culture, 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 the nutrient solution's proximity 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 straightforward and efficient hydroponic system, making it a popular choice for beginners and small-scale growers. It is also a highly efficient system, as the nutrients in the water solution can be directly absorbed by plants without the need for soil or other growing media. However, deep water culture can be difficult to set up and keep up because it needs close attention to 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

Another type of hydroponic cultivation is the NFT system, which uses a thin film of nutrient solution to continuously flow 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 surplus nutrient solution is subsequently gathered and returned to the reservoir in order to reduce wastage. The NFT system is commonly used for growing crops like lettuce, herbs, strawberries and spinach[4].

3) Drip System

A popular hydroponic technique, the drip system consists of a network of emitters and tubes that are used to gradually supply plants with nutrient-rich water. This system utilizes a timer-controlled pump to ensure regular intervals of nutrient solution are dripped onto the plants' roots, providing a precise and controlled delivery of essential nutrients. By collecting and recirculating the excess solution back to the reservoir, the drip system minimizes waste. Its adaptability enables the cultivation of a wide range of crops, including tomatoes, peppers, cucumbers, and spinach. The Freight Farms hydroponic organization has even developed a recirculating drip system specifically designed for their container, which efficiently utilizes 5,000 crops that can be grown with less than 5 gallons of water per day.[5].

4) Dynamic Root Floating Technique (DRFT) System

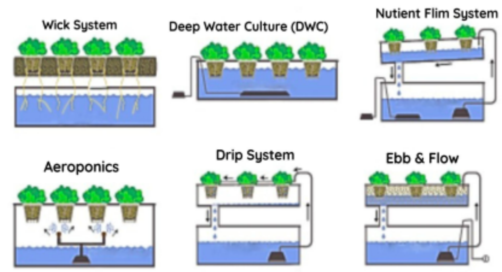
In the DRFT system, a kind of hydroponic farming, nutrient solutions are continuously pumped through the roots of the plants at a fixed depth within the planting tray. This system ensures continuous nutrient supply to the plants and is implemented in agriculture with the hydroponic DRFT model. The roots of the plants in the DRFT system are suspended in the nutrient solution and are arranged in a panel. The nutrient solution is continuously circulated through the tray, providing the plants with the necessary nutrients for growth. This system is frequently used to cultivate 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 flood and drain system, also called the EBB and Flow system, is a technique in which nutrient solution is periodically flooded into the roots of plants and then drained out. This cyclic process ensures proper nutrient uptake by the plants and can be automated using various control technologies. This system involves placing the plants in pots or trays and pumping nutrient solution into the tray to submerge 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. Because of its adaptability, the EBB and Flow system can be used for growing a wide range of plants such as cucumbers and melons[7]

6) Wick System

The wick system is a type of passive hydroponics where the nutrient solution is moved from a reservoir to the roots of plants via a wick. Plants in the wick system are set in a growing medium, like 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. Typically, the reservoir's nutrient solution is a blend 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 established sustainable agricultural methods for space missions by experimenting with crops such as soybeans, wheat, tomatoes, and lettuce. The agency has also developed a life support system for space that can support the oxygen needs of a single person for every 20-25 square meters of crops grown.[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)

The EC/TDS ratio measures the concentration of dissolved salts in a nutrient solution. Monitoring and adjusting EC/TDS levels make sure that plants get the right amount of nutrients for optimal growth. High EC/TDS levels can lead to nutrient imbalances and toxicity, whereas insufficient amounts may lead to dietary deficits. By maintaining the appropriate EC level, nutrient imbalances can be avoided, preventing nutrient deficiencies or toxicities. The nutrient solution's EC level shows 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

The pH of a nutrient solution indicates its acidity or alkalinity. It is a critical parameter that needs to be monitored and controlled in hydroponic systems since it has an impact on the availability and uptake of nutrients by the plants. Most plants grow best in a pH range of 5.5 to 6.5, which is slightly acidic to neutral. 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].It's critical to maintain the proper pH level because an improper pH can result in 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 A peristaltic pump is activated to enhance pH levels if the pH falls below 6.2. Conversely, if the pH rises above 7.5, the pump adds base to decrease the pH.

3. Temperature

Temperature has a significant impact on plant growth and metabolism. It affects nutrient uptake, enzymatic activity, and overall plant health. Different plants have different temperature preferences, but for the majority of hydroponic crops, a temperature range of 18–25°C (64–77°F) is appropriate. 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 affects photosynthesis, respiration, and transpiration, among other physiological functions in plants. 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 required for photosynthesis, which is the process by which plants transform light energy into chemical energy. In DWC hydroponics, controlling light intensity is crucial to provide plants with the right amount of light to support photosynthesis and encourage robust plant development. 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. In a related study, the photosynthesis effect of 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 was successfully experimented upon in a "Brassica Chinensis" plant.[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. Although different plants have different humidity requirements, most hydroponic crops do best in a range of 50–70% humidity. A relative humidity (RH) of 40–60% is ideal during the transition from the germination to the vegetative phase, and during the blossoming phase. Low humidity levels can increase transpiration rates, leading to water stress and wilting. Conversely, high humidity levels can create a favorable environment for fungal diseases and impede transpiration, resulting in decreased 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

In hydroponics, the nutrient solution supplies vital minerals and nutrients that plants need to grow. To ensure that the nutrient solution meets the unique needs of the plants being grown, it must be regularly monitored and adjusted. This entails giving the proper ratio of micronutrients (like iron, zinc, and manganese) to macronutrients (like potassium, phosphorus, and nitrogen). 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 guarantees that plants receive the appropriate nutrients at the appropriate times, 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 several elements including the amount of light, temperature, humidity, water level, pH levels, TDS, and concentration of nutrients in the hydroponic system. These sensors provide accurate and real-time data, enabling farmers to decide with knowledge 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 evaluate the information and decide how to change 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 the Internet of Things (IoT) is a network of connected devices that can exchange data and communicate with one another and it is a technology that used to connect sensors, actuators, and control systems, enabling real-time monitoring and control of various parameters like 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 numerous data from sensors and other sources. Data analysis methods like data mining and machine learning can be applied to this data to extract useful insights. 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 ambient conditions can be classified as The spatial, vertical, and temporal. These variabilities are important for optimum cultivation. A Korean study conducted by Chungnam National University discovered that Ambient temperature rose from 1200 to 1400 hours and continued to do so, while Relative humidity(RH) readings linearly changed through the experiment. When one of the side windows was open, the drop between the Max and Min values of temperature and RH readings was larger than when direct ventilation was closed. The Max and Min value measurements were also at different locations and heights, and PPF and CO2 concentrations varied with time, height, and location. The highest Photosynthesis Photon Flux readings were seen at a height of 3 meters, in the vicinity of the light source and CO2 distribution[24].

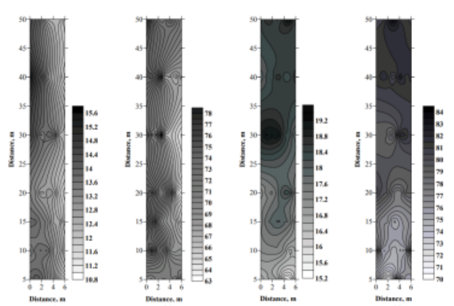
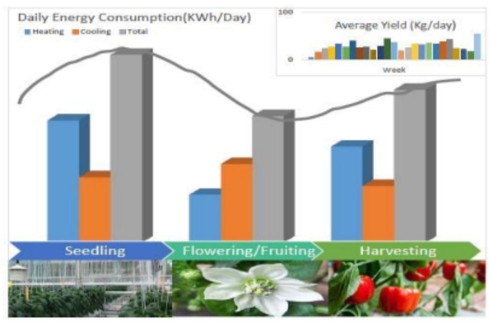


Figure 6. Spatial distribution of air temperature and humidity at a 0.5-m height in greenhouse 1 : (a) air temperature and (b) RH with the right side window open at 12:00, and (c) air temperature and (d) RH with the both windows closed at 14:00.

2) Time and season-based variations

The variance in energy use in plantations occur since certain parameters must be controlled to specific range this includes temperature, relative humidity and so on. As per a government-funded study in Australia, the following observations were made. The total power consumption for heating in this case used for the hot water system and cooling in this case through pad and fan, during the crop cycle was reported as 12,503 kWh and 5,183 kWh, respectively. This indicates that heating accounted for the majority of the energy used in the observed 8-month nurturing and farming period, which spanned from onslaught of spring to end of autumn in a plantation facility. Regression algorithms showed that daily energy consumption varied within each season, with heating requiring 14.62 kWh per 1 °C increase and cooling using 2.23 kWh per 1 °C decrease [25].



3) Controlled and uncontrolled parameter fluctuations

In most studies, temperature, humidity, soil moisture, light intensity, and CO2 are crucial factors that are typically controlled. However, these parameters are not evenly distributed throughout a plantation, which can significantly impact crop growth. To address this issue, a study funded by the Korean government proposes various control systems using multiple sensor nodes to establish a stable thermodynamical environment for plantation. Experimental samplings and verifications were carried out at different scales to evaluate the effectiveness of these systems.

Furthermore, a WSN's(Wireless Sensor Network) introduced for enhancing the sensing as well as actuators systems, providing a higher spatial resolution. This allows for more precise observation and measurement of the aforementioned control variables.[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 important to store the generated energy in storage devices similar to 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, and system complexity are all some technical constraints that must be taken into consideration while building any embedded system. Data security and human Interventions are other aspects of design as it must be understood that not every security solution provides a similar level of security towards diverse types of attacks and malicious parties that exist, on the contrary, each and every solution must be created and/or modified for any and all particular type of threats that arise. However, this leads to those solutions having a narrow scope. but they tend to give better performance just an all-encompassing scope. Depending on the proposed hydroponics we need to make respective changes[30].

4) Reducing Water Use And Discharge To The Environment

Long-term studies on the management of zero agricultural discharge systems have not been conducted, which hinders the provision of growers with definitive guidelines for system management. While these systems have the capacity to safeguard groundwater, streamline the process of obtaining water permits, and support the long-term viability of agricultural operations, the lack of extensive research hampers the establishment of definitive protocols[31].

5) Chemical compound Management Of Nutrient solution In The Hydroponic Solution

Solution chemistry is of utmost importance when it comes to ensuring that hydroponic systems maintain optimal nutrient concentrations for plant uptake. When preparing nutrient solutions from salts or concentrated liquid stocks, it becomes crucial to carefully take into account specific chemical equilibria. One particularly significant equilibrium that must not be overlooked is the solubilization-precipitation equilibrium. Ignoring this equilibrium could have detrimental effects on the overall success of the hydroponic system. Hence, it is imperative to pay close attention to the solubility of the various salts in order to ensure that the nutrients remain in a soluble form, readily available for plant uptake. By considering and managing the solubilization-precipitation equilibria, hydroponic growers can optimize nutrient availability and thereby promote healthy plant[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 imperative for long-term space initiatives , well being and 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 utilization of brackish water (meaning water occurring in a natural environment that has more salinity than freshwater, but not as much as seawater) in agriculture may cause the soil's salt content to rise, which may have a adverse effect on plant output. However, adopting hydroponic cultivation techniques can help to mitigate this issue. Hydroponics is a technique that includes growing plants in a nutrient-film solution rather than soil driven. 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) Machine learning 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. ML algorithms tend to make the decision based on the features and their respective 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, CO_2 levels, nutrient solution composition, substrate characteristics, and dissolved oxygen levels are investigated. . The paper reviews sensor technology, actuator technology, control systems, IoT integration, as well as 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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