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SMART SPROUT – AN IOT INTEGRATED HYDROPONIC SYSTEM

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Abstract : Agriculture has been a major part of human civilization since ages. The traditional farming methods are dependent on availability of arable land, water resources and are subjected to soil degradation and unpredictable climatic conditions. Hydroponic farming offers a promising alternative, providing a controlled environment for plant growth without relying on soil. Implementing IoT-based solutions, enables precise monitoring and management of hydroponic systems, leading to improved efficiency, sustainability, and yield in controlled agricultural environments. In this paper a vertical hydroponic farming system is implemented which overcomes the space constraint of traditional farming. The highlight is the proposed automation system which incorporates Node MCU microcontroller interfaced with Blynk IOT which integrates sensor nodes; DHT11 for monitoring atmospheric humidity and temperature, DS18B20 and Peltier module for temperature monitoring, control of nutrient concentration along with pH sensor and grow lights. The system is implemented to monitor kale, Arugula, Lettuce plants and the temperature ranges (25^0 -30^0 C), optimal pH value (5.5) and ideal nutrient solution temperatures are tabulated. The results are validated and it is found that the proposed automated system is more efficient compared to the basic hydroponic farming. The proposed smart IoT system refines and optimizes the conventional hydroponic farming by continuous monitoring; paving the way for sustainable agricultural practices.

***IndexTerms* – Hydroponics, Node MCU Esp2866, Arduino IDE, Blynk IoT, nutrient solution, sensors.**

1. INTRODUCTION

Hydroponic farming is a popularly used technique for growing plants without soil using nutrient-rich solution for better yield and efficient cultivation. This method accurately controls the environmental conditions such as temperature, light and nutrients to optimize plant growth and productivity [1]. Hydroponics can be adjusted to various environments and requirements, with applications ranging from urban agriculture in rooftop gardens and indoor farms to large-scale commercial agriculture in climate-controlled greenhouses. The Hydroponic farming system deals with challenges encountered in traditional farming such as soil degradation, water scarcity, pest management, and climate dependence. It enables the efficient utilization of limited space, making it possible to grow fresh produce in rooftop gardens, vertical farms, and indoor facilities. The increasing requirement for local and organically produced food, in densely populated cities is also addressed. There are various hydroponic techniques, each with its unique way of supplying water, macro and micro nutrients to the plants. The most widely used Hydroponic Technique is the Nutrient Film Technique (NFT), which grows plants in a shallow stream with essential nourishment, while in the Ebb and Flow method the flooding and draining of the nutrient solution is done at periodic intervals to provide maximum efficiency [2]. As an improvement over the conventional system, vertical hydroponic systems are preferred for their efficient use of space and resources, making them suitable for urban and small indoor environments. This system maximizes the crop yields per square foot and utilizes water, nutrients and light more efficiently compared to horizontal hydroponic farming.

Integrating IoT technology with vertical Hydroponic farming, enables precise control over environmental factors, optimizes the resources and provides maximum crop yield [3]. The Hydroponic systems are deployed in challenging environments, such as deserts or disaster relief zones, where it offers a reliable source of fresh food. The applications of the IoT-based hydroponics system are diverse and impactful across various sectors. In urban agriculture, these systems enable the efficient utilization of limited space, making it possible to grow fresh produce in rooftop gardens, vertical farms, and indoor facilities. Commercial agriculture benefits from the scalability and precision of IoT-based hydroponics, with large-scale farms maximizing the crop yield with minimum usage of resources. Additionally, IoT-based hydroponics provides valuable data on plant growth, nutrient requirements and environmental conditions which can be used for research and development in agriculture. Overall, the

applications of IoT-based hydroponics span from urban farming to commercial agriculture, research, education, and disaster response, demonstrating its versatility and potential to address global food security challenges [5].
The literature survey suggests various hydroponic techniques; but few focus on vertical implementation of hydroponic farming [4]. In this paper, vertical hydroponic farming is implemented and its automation is achieved to optimise the performance. In the proposed system, the sensors are interfaced using Arduino IDE software and embedded C++. The remote monitoring and control are achieved by integration with Blynk IoT. The paper is organised as follows. The system is introduced in section 1; section 2 describes the various works done earlier and the evolution of hydroponic farming. The section 3 describes the block diagram of the Hydroponic system. The section 4 illustrates the proposed Smart Hydroponic system and the workflow is elaborated in section 5. The section 6 describes the implementation results and section 7 has the Conclusion and Future scope.

2. LITERATURE SURVEY

The basic hydroponic farming techniques have been described in various papers [11], [12]. The automation is introduced in successive years and the evolution of hydroponic framing is briefly summarized. The Table 2.1 shows hydroponic farming techniques with their advantages and disadvantages.

Table 1 Review of Hydroponic Farming Techniques

Papers	**Year**	**Sensors**	**Advantages**	**Disadvantages**
Automated pH Controller System for Hydroponic Cultivation (Saaid M.F et al.)	2015	Water level sensor, pH sensor	The pH levels of water monitoring and its control methods are described .	Implements The Deep Water Culture (DWC) technique.
Integrating Scheduled Hydroponic System (Dr. S. Umamaheswar et al.)	2016	Water level sensor, pH sensor.	Improvises the growth of crops rapidly	Only Single type of crops can be used.
Automation of Hydroponics Greenhouse farming using IOT (Dr. D. Saraswathi et al.)	2018	Temperature sensor, humidity sensor, Ph sensor and pressure sensor.	The system focuses on automating the monitoring of the greenhouse environment and maintaining optimal pH levels and electrical conductivity.	The system lacks a discussion on how the humidity, temperature, and pressure, control the growth of the plant.
Smart Hydroponics Water Monitoring Using IoT (P.Nagamani et al.)	2019	DS18B20 Sensor, DHT 11, pH sensor, Turbidity sensor.	Continuous monitoring of the plant growth parameters.	High installation costs and the need to test the solution frequently.
Development and Monitoring of Hydroponics using IoT (Pavan Koge et a)	2020	DHT 11 sensor, water temperature sensor, pH sensor, grow lights.	Consistent monitoring of water supply, temperature, nutrients, humidity and other important parameters.	It does not consider the parameters such as air quality, which affect the plant's growth.
Hydroponics System based on IoT(Anupama A Kori1 et al.)	2021	Temperature sensor, humidity sensor, pH level sensor	Increases agricultural crop production.	High Initial setup costs and technical expertise are required for implementation.
IoT-based control and monitoring system for hydroponics Greenhouses (Konstantinos Tatas)	2022	Water quality sensor and Electrical conductivity (EC) sensor.	Convenient monitoring of greenhouse remotely.	Limited information on the scalability of the system.
Fuzzy Logic Control based IoT based system (Meida Cahyo Untoro et al)	2022	Temperature sensors, pH sensors, color sensors and nutrient concentration sensors.	Fuzzy logic enables a decision-making process that mimics human thinking.	Drawbacks associated with the fuzzy logic control
Hydroponic Smart Farm System with Web-based IoT. (T. Irfan Fajri et al)	2022	Light sensor and pH sensor.	Enables precise control of irrigation and fertilization.	Potential security vulnerabilities.
Hybrid IoT-based indoor hydroponicsfarming.(Omolola ogbulumani)	2023	Macro, Microenvironment sensor sets, Water sensor sets	It integrates both wired and wireless elements.	Complex process of initial setup and configuration.

3. HYDROPONIC FARMING

Hydroponic farming, is a modern agricultural technique where plants are grown in nutrient solutions, that provides all the essential nutrients for growth and eliminates the use of soil. However, its modern applications emerged in the mid-20th century with the integration of technology [6]. The primary principle behind hydroponic farming is to provide optimal conditions for growth to the plants while maximizing resource efficiency. By eliminating soil, hydroponic systems can precisely control factors such as nutrient levels, pH balance, and water availability, resulting in ideal plant growth conditions thereby producing higher yields. Hydroponic farming allows the cultivation of crops in areas with poor soil quality, unfavorable weather conditions and limited arable land. Hydroponic systems are more advantageous in areas with water scarcity and drought prone regions and are more suitable than the basic cultivation methods. Furthermore, hydroponic farming enables year-round cultivation and can be modified to specific crop requirements, leading to consistent production and higher-quality produce. This versatility has made hydroponics a preferred choice for growing a wide range of crops.

3.1 CLASSIFICATION OF HYDROPONIC FARMING TECHNIQUES

The classification of hydroponic farming techniques involves categorizing them based on various factors such as the medium used, nutrient delivery method, system design and technological advancements [7].

Nutrient Film Technique

The Nutrient Film Technique (NFT) is a widely used simple and efficient hydroponic farming method. In NFT the plants are submerged in a thin film of nutrient solution which flows steadily over the roots providing them with the essential nutrients, oxygen and water.

Deep Water Culture

Deep Water Culture (DWC) is a hydroponic method where oxygenated nutrient solution is filled in the nutrient reservoir and the plant roots are suspended in it. Unlike other hydroponic systems, DWC involves submerging the roots in a deep reservoir of water, which continuously supplies the plants with crucial elements for its growth. This method is particularly favored for its simplicity and effectiveness in growing large plants quickly.

Drip System

In the drip irrigation hydroponic system, there is a network of emitters and tubes through which the essential nutrients are provided to the roots of the plants in a slow and steady manner. In this system, the water supply and nutrients are efficiently delivered.

Ebb and Flow

Ebb and Flow, This hydroponic technique is also known as the Flood and Drain method in which the nutrient-rich water is periodically fed to the plants and then drained back into the reservoir. This cyclic flooding and draining process ensures that plant roots receive ample nutrients, water, and oxygen. This system is more suitable and better comparatively and hence, widely used.

4. PROPOSED SMART HYDROPONIC SYSTEM

The proposed IoT-based hydroponic system is integrated with Blynk IoT via a WiFi network, enables remote monitoring and control. The system interfaces with the hydroponic setup to monitor and control various parameters. The main purpose of this integration is to ensure that the plants are provided with optimal growing conditions continuously by automating key processes such as nutrient level maintenance, temperature regulation and pH balance. The system continuously monitors the water temperature to ensure no inhibition in plant growth [8]. Additionally, it keeps track of the ambient temperature around the plants. If the temperature exceeds 32 degrees Celsius, the system takes corrective actions, such as turning off the grow lights to prevent stress and overheating on the plants. The Figure 1 shows the circuit diagram of the implemented system.

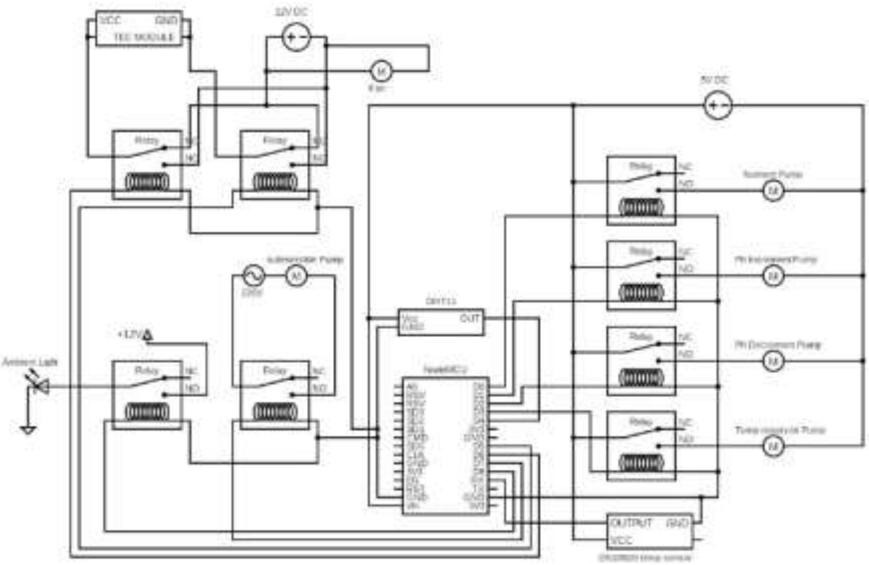

Fig 1 Circuit Diagram of Hardware Connections

The important components of the proposed system include the DHT11 sensor for monitoring atmospheric temperature and humidity. This real-time monitoring helps maintain a stable growing environment, crucial for plant health and growth. The system employs a water temperature sensor, Thermoelectric Cooler (TEC) module, heat sink, and fan to monitor and maintain ideal temperatures of nutrient solution for plant growth. The nutrients are circulated and accurately controlled using multiple pumps and relays. pH adjustment and distribution of water are integrated. Grow lights provide the necessary light for photosynthesis, especially in indoor settings, ensuring that plants can thrive even without natural sunlight [10].

In the proposed system the mentioned parameters of the hydroponic system are continuously monitored and remotely accessed using IoT technology. Moreover, the system oversees the pH levels, essential for nutrient intake by the plants [15]. If the pH level deviates from the optimal range (exceeding 5.5), the system adjusts the nutrient solution to bring the pH back to the desired level [9]. This automated pH regulation ensures that plants can absorb nutrients efficiently, promoting better growth and health. The hydroponic system operates on the ebb and flow method by periodically flooding the roots of the plant with nutrient-concentrated water and later draining it away. This method ensures plants receive an optimum growing environment throughout the crop cycle. The Node MCU, programmed using Arduino IDE and embedded C++, acts as the system's central control unit, interfacing with various sensors and relays to manage the environment. Integration of the system with Blynk IoT, allows users to remotely monitor and control it through the internet.

The Figure 2 shows the block diagram of the proposed hydroponic system with DHT11, DS18B20 and pH sensors. The additional interfaces in the proposed system are Thermo Electric Cooler (TEC) module and LED grow lights. The different blocks of Figure 2 are briefly described.

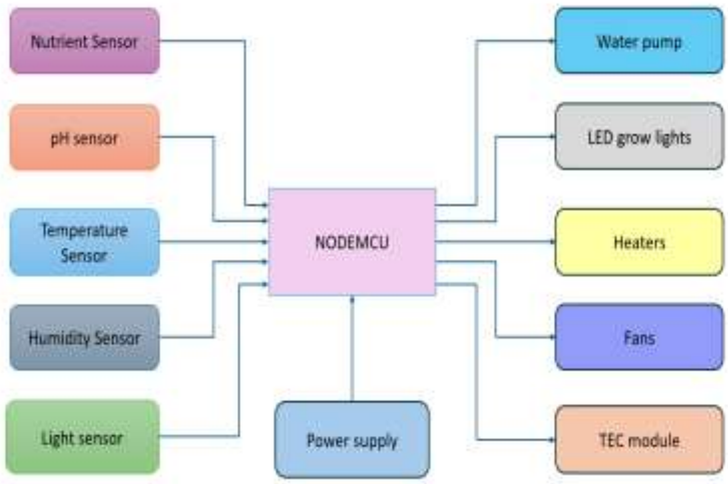

Fig 2 Proposed Hydroponic System

Sensors

The various sensors interfaced in hydroponic system are the pH sensor, DHT11 sensor and water temperature sensor. The pH level of the nutrient solution is monitored by using a pH sensor in the hydroponic system. The DHT11 sensor monitors the atmospheric conditions of the growing environment. This sensor provides real-time data on temperature and humidity levels, allowing the user to assert optimal growing conditions for plants. The Water Temperature Sensor measures the temperature of the concentrated nutrient solution. Temperature affects plant metabolism and nutrient uptake. This sensor helps maintain the nutrient solution at the optimal temperature range for plant growth, preventing temperature-related stress or damage to the plants.

Node MCU

Revolutionizes hydroponic systems by leveraging its Wi-Fi connectivity and sensor integration capabilities. Acting as a central hub, it enables real-time monitoring of crucial environmental parameters like pH, atmospheric temperature and humidity, and nutrient solution temperature. Growers can remotely access this data, make informed decisions, and automate tasks such as nutrient dosing and irrigation schedules. Node MCU also provides alerts for abnormal conditions, empowering growers to take timely actions to maintain optimal growing conditions. With seamless integration into IoT platforms, Node MCU offers advanced analytics and control options, streamlining operations and maximizing crop yields in hydroponic cultivation.

Thermoelectric Cooling Module

A thermoelectric cooling (TEC) module is also known as a Peltier device. By leveraging the Peltier effect, TEC modules is used to both heat and cool surfaces when electric current flows through them [13]. In hydroponics, this module can regulate the temperature of nutrient solution. During warmer periods, TEC modules can cool the nutrient solution, preventing overheating and maintaining an optimal temperature range for plant growth by working in reverse bias. Conversely, in colder climates or during cooler periods, they can warm the solution, safeguarding plants against temperature drops that could affect growth by working in forward bias.

Water Pumps

Submersible water pumps play a fundamental role in hydroponic systems in which the nutrient solution is circulated to the roots of the plants. These pumps dispense the water through their containers. The submersible pump ensures that roots receive uninterrupted nutrient supply simultaneously maintaining a continuous water flow. This stimulates healthy root development and optimal growth. Their compact design and quiet operation make them ideal for indoor hydroponic setups, where space and noise considerations are important.

Grow lights

Grow lights are vital for hydroponic systems, providing artificial light to support plant growth in indoor or low-light environments. LED grow lights are commonly used for their energy efficiency and customizable spectra, ensuring consistent and adequate light exposure for plants; promoting healthy growth and maximizing the yield in hydroponic cultivation.

5. SYSTEM WORKFLOW

This workflow outlines the sequence of actions taken by the smart hydroponic system to monitor and control key parameters such as water level, temperature, pH level, grow lights and nutrient supply. By following these steps, the system ensures optimal growing conditions for plants while providing real-time monitoring and control to the user. [16]The Figure 3 shows the flowchart and stepwise explanation of the proposed hydroponic system.

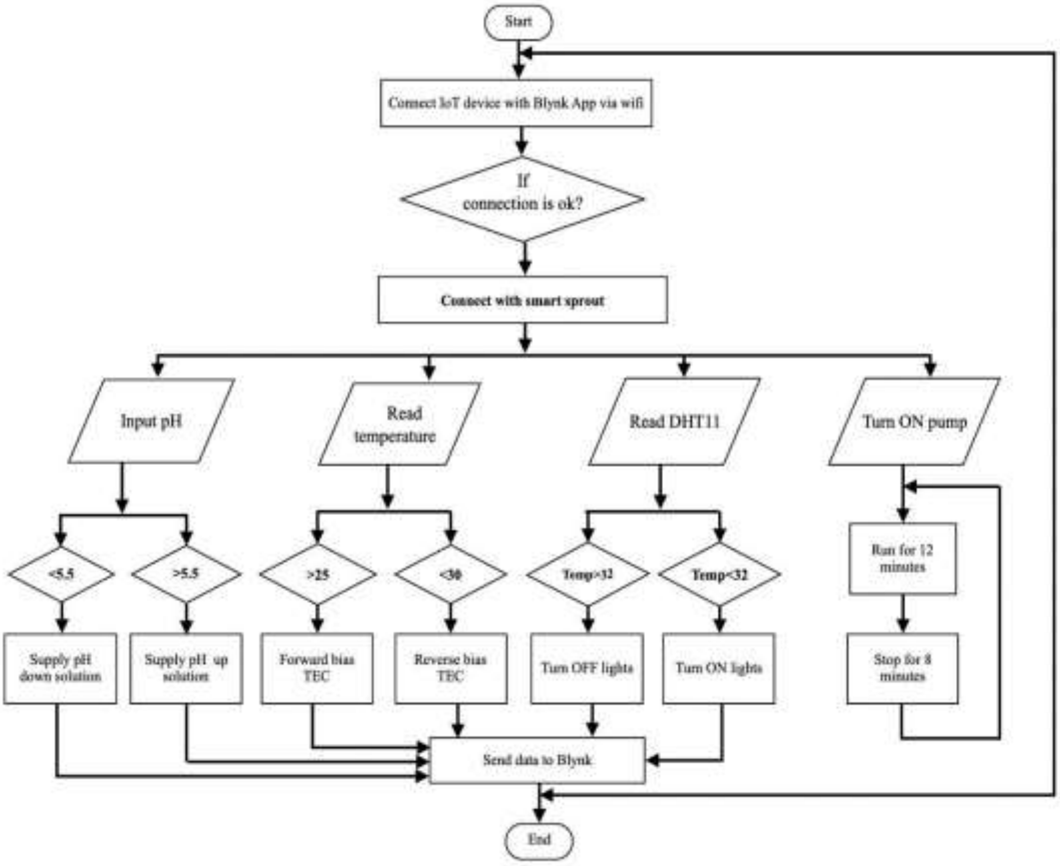

Fig 3 System Workflow

Initialization

At the onset of the program execution, the IoT device establishes a connection with the cloud server via a Wi-Fi network. This step serves as the foundation for enabling communication and data exchange between the hydroponic system and the cloud-based monitoring and control platform, Blynk IoT.

Connection Establishment

Following the initialization phase, the program verifies whether the connection with the cloud server is successfully established. This step ensures seamless communication between the IoT device and the cloud server facilitating the exchange of real-time data and instructions for monitoring and managing the hydroponic system.

Hydroponic System Connection

Upon successful connection with the cloud server, the program proceeds to establish a connection with the hydroponic system itself. This step enables the IoT device to interact directly with the hardware components of the hydroponic setup, including sensors, actuators, and control systems, thereby enabling precise monitoring and control of key parameters.

Temperature Monitoring

Simultaneously, the program monitors the ambient temperature within the growing environment. Should the temperature exceed the predefined threshold of 32 degrees Celsius the system turns off the grow lights to prevent overheating and stress on the plants.

Water Temperature Monitoring

Additionally, the program continuously monitors the temperature of the Nutrient Solution . If the temperature exceeds 30 degrees celsius the TEC module is reverse biased and if it drops below 25, The TEC module is forward biased to maintain optimal growing conditions for the plants

pH Level Monitoring

Another crucial aspect of hydroponic farming is maintaining the appropriate pH level of the nutrient solution. The program continuously monitors the pH level and adjusts the pH to optimal level i.e, 5.5.

Nutrient Pump

The nutrient pump is run for 12 minutes and then paused for 8 minutes in an infinite loop ensuring efficient delivery of nutrients to the entire hydroponic system.

End of Program

As program completes its monitoring and control tasks, it marks the end of its execution cycle.

6. RESULTS AND DISCUSSION

The Smart IoT-based hydroponic system is interfaced with different sensors and implemented using Blynk IoT. The plants considered for evaluation are Kale, Arugula, and Lettuce. The optimal conditions for the plants grown in the smart hydroponics system are obtained by utilising the linear regression model using the favorable conditions as shown in Table 2 [14].

Table 2 Favorable conditions

Plants	pH level	Atmospheric temperature(^{0}C)	Nutrient Solution temperature (^{0}C)	Humidity(%)
Kale	5.5-6.5	24-28	25-30	40-60
Arugula	6.0-6.5	21-24	25-28	30-50
Lettuce	5.5-6.5	17-28	20-26	30-40

The formula for predicting the growth rate y' in terms of pH, temperature and Nutrient Solution Temperature is given as:[14]

$$y' = \theta_0 + \theta_1 \cdot pH + \theta_2 \cdot EC + \theta_3 \cdot temperature + \theta_4 \cdot$$

Where: θ_0 is the intercept of the regression model. θ_1 , θ_2 , θ_3 , θ_4 are the coefficients corresponding to the features pH, Atmospheric temperature, and Nutrient Solution temperature, respectively. The optimum values for plant growth produced by the linear regression model are summarized in Table 3.

Table 3 Optimal conditions

S.No	pH values	Atmospheric Temperature	Nutrient Solution Temperature	Humidity
1.	5.5	32^{0}C	25^{0}C-30^{0}C	50%-70%

The Hydroponic System is implemented as seen in Figure 4. The entire system is controlled by relays. The connections are encased in a box enclosure as shown in Figure 5 to prevent any damage to the system.

Fig 4 Vertical Hydroponic System

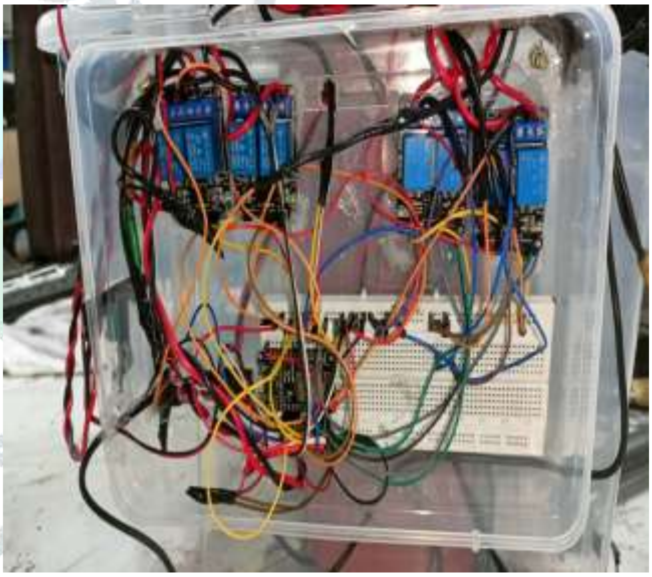

Fig 5 Circuitry of the system

The Temperature sensor and Ph sensor are immersed in the nutrient reservoir to record and observe the temperature and pH level of the nutrient solution. Additionally, The TEC module sensor is mounted upon the reservoir to adjust the temperature of the water. This is achieved by running the module in forward bias to heat the water and in reverse bias to cool down the water to maintain an ideal temperature. Integration of DHT11 enables monitoring of atmospheric temperature and adjustment of ambient lighting. Two-channel relays are used to control the entire system. The performance of the proposed smart hydroponic system is evaluated in terms of metrics such as Yield per square foot, Water usage in terms of gallons and Cycle Harvest time in terms of number of days. The metrics obtained for Smart Sprout are compared with a basic hydroponic system.

Yield Per Square Foot

The IoT-based system Smart Sprout observes the highest Yield per Square foot comparatively to all the plant specimens as shown in Figure 6. The Yield is observed to be three times that of Basic Hydroponic farming practices.

Table 4 Yield per Square Foot

Plants	Basic Hydroponic System (pounds)		Smart Sprout (Gallons)	
	Min	Max	Min	Max
Kale	2	3	3	4
Arugula	1.5	2	2	2.5
Lettuce	1.5	2	2	2.5

The Table 4 depicts the Yield obtained from the produce of Kale, Arugula and Lettuce from a basic Hydroponic System and Smart Sprout. It is noted that Smart Sprout has produced better yield quantity compared to a basic Hydroponic System.

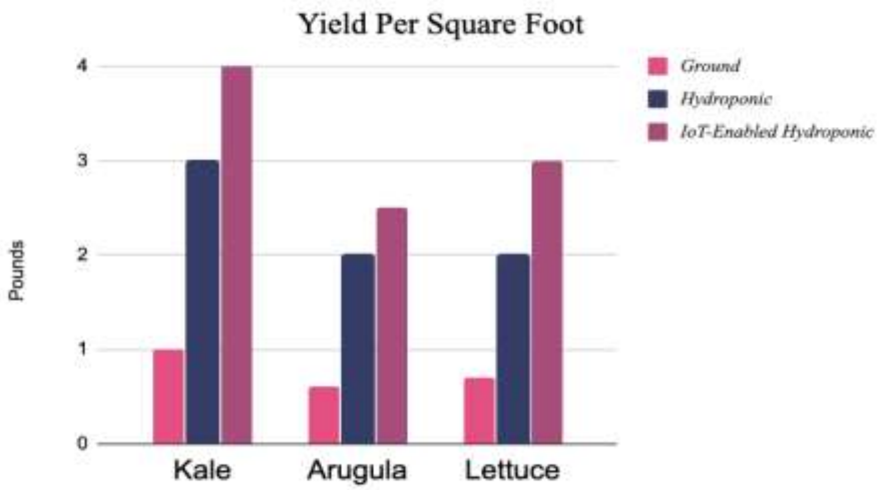

Fig 6 Yield Per Square Foot Graph

Water Usage

It is observed that growing plants in ground traditionally, requires the most amount of water. The comparison can be seen in Figure 7. It is observed that Smart Sprout is the most efficient system in terms of water usage.

Table 5 Water Usage in Gallons

Plants	Basic Hydroponic System (pounds)		Smart Sprout System (Gallons)	
	Min	Max	Min	Max
Kale	5	7	3	5
Arugula	4	6	2	4
Lettuce	3	5	2	3

It is observed in Table 5 that Smart Sprout uses the least amount of water for cultivation. Whereas the Basic Hydroponic System uses a significant amount of water comparatively.

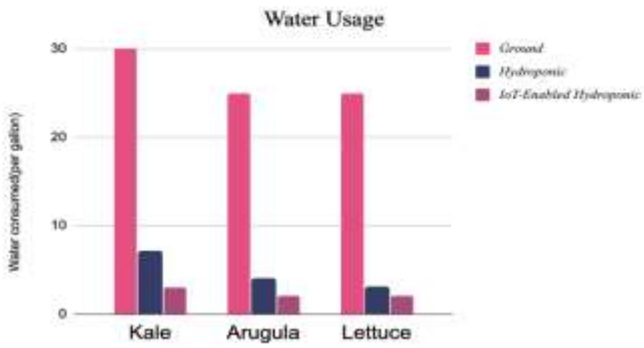

Fig 7 Water Usage

Cycle Time

It is observed that with the help of Smart Sprout, The time to harvest the plants has been reduced to half when compared to other methods of cultivation this can be observed in the Figure 8.

Table 6 Cycle Harvest Time in Days

Plants	Basic Hydroponic System (Days)		Smart Sprout (Days)	
	Min	Max	Min	Max
Kale	30	45	25	35
Arugula	20	25	15	20
Lettuce	30	40	25	30

The days taken to harvest a single cycle of each vegetable gown can be observes in Table 6 for both basic Hydroponic System and Smart Sprout. It is observed that Smart Sprout reduces the Cycle time notably. Reducing the crop cycle time allows to

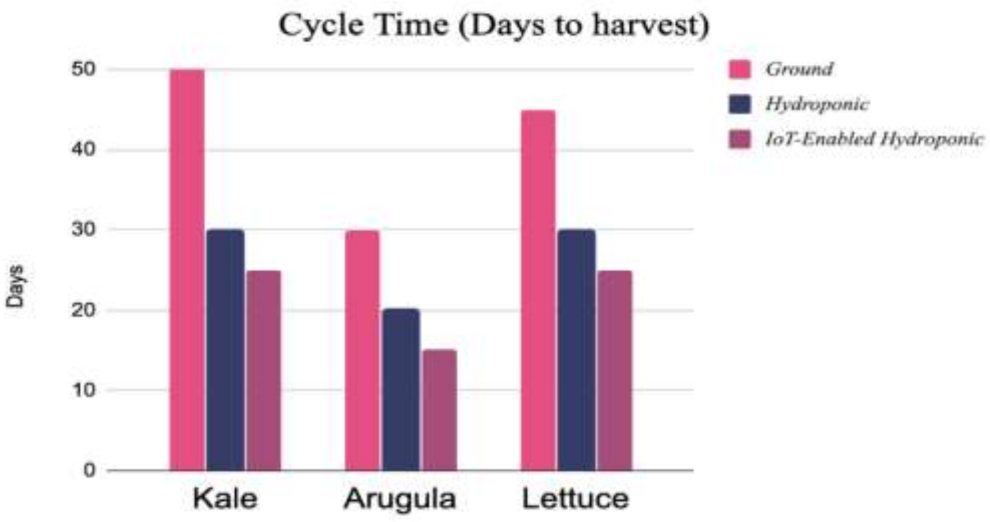

Fig 8 Cycle Time

Growth Rate

The growth parameter of three various seeds Kale, Arugula and Lettuce has been compared as shown in the Figure 9 Traditional farming, A basic hydroponic system and Smart Sprout An Intelligent Hydroponic system are studied. It is observed that Smart Sprout exhibits the highest growth rate amongst all.

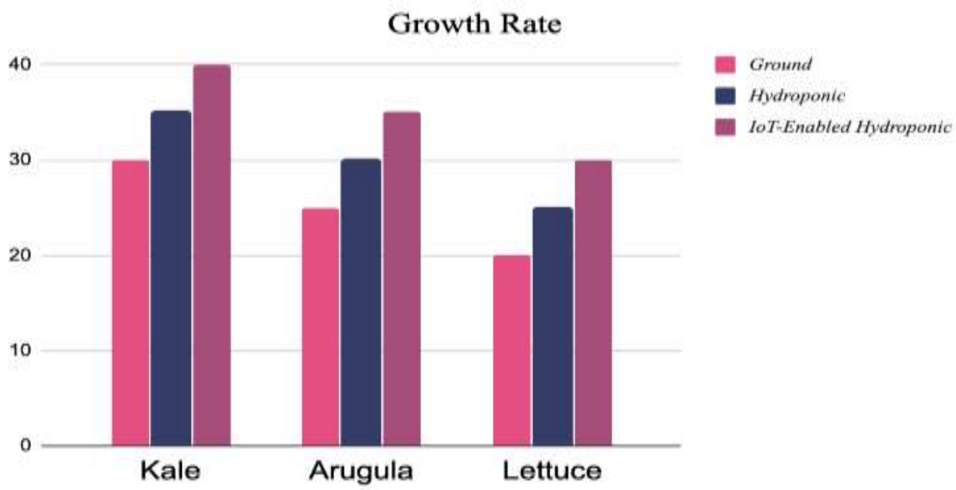

Fig 9 Growth Rate Graph

Pest and Disease Incidence

Smart Sprout experiences the least amount of pest and disease incidence due to its eradication of soil usage thereby ruling out any soil borne diseases. The Figure 10 shows the Pest Disease Incidences on various systems.

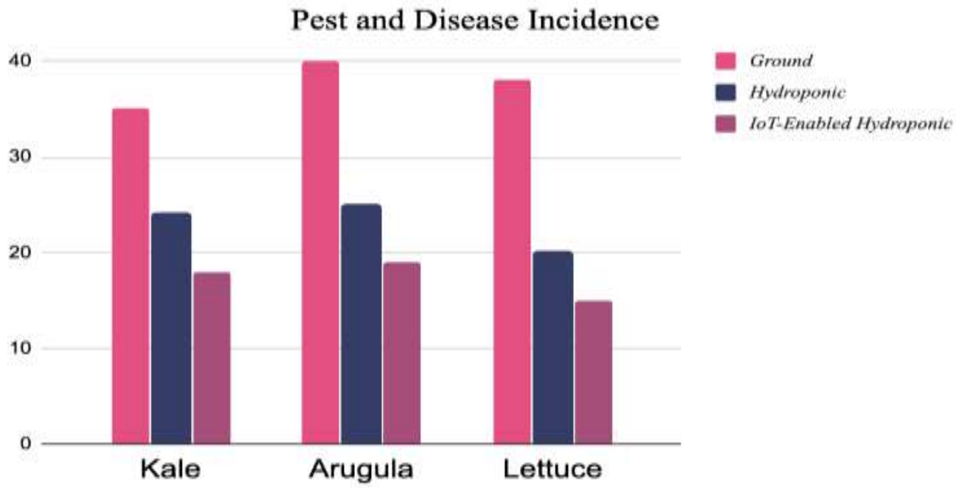

Fig 10 Pest and Disease Incidence

Nutrient Efficiency

The nutrient efficiency for various systems that have been considered can be observed below in Figure 11. It is observed that Smart Sprout delivers maximum nutrients to the root system. The solution filled with nutrients is synthesized considering all the plant requirements and essential macro and micronutrients. It is directly supplied to the plants ensuring efficient delivery of nutrients and its absorption.

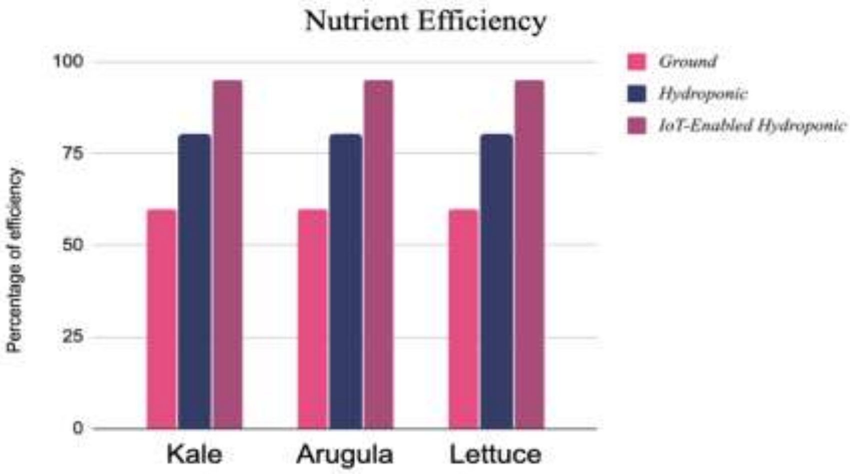

Fig 11 Nutrient Efficiency

Table 7 Comparison of Parameters for various systems

Parameters	Ground Farming	Basic Hydroponics System	Smart Sprout System
Growth Rate	Moderate growth rate, depends on soil quality, climate, and weather conditions.	Faster growth rate due to optimized nutrient delivery.	Fastest growth rate, with real-time monitoring and adjustments ensuring optimal conditions at all times.
Pest and Disease Incidence	High, with significant dependence on pesticides and disease control measures.	Lower than ground, but still requires monitoring and occasional intervention.	Lowest, with real-time monitoring since a controlled environment and regular interventions are made.

Web Dashboard

The Web Dashboard with additional control widgets for nutrient Pump, Light Settings and nutrient dosing are added as seen in Figure 12. The Dashboard also displays the Water Temperature and Atmospheric Temperature.

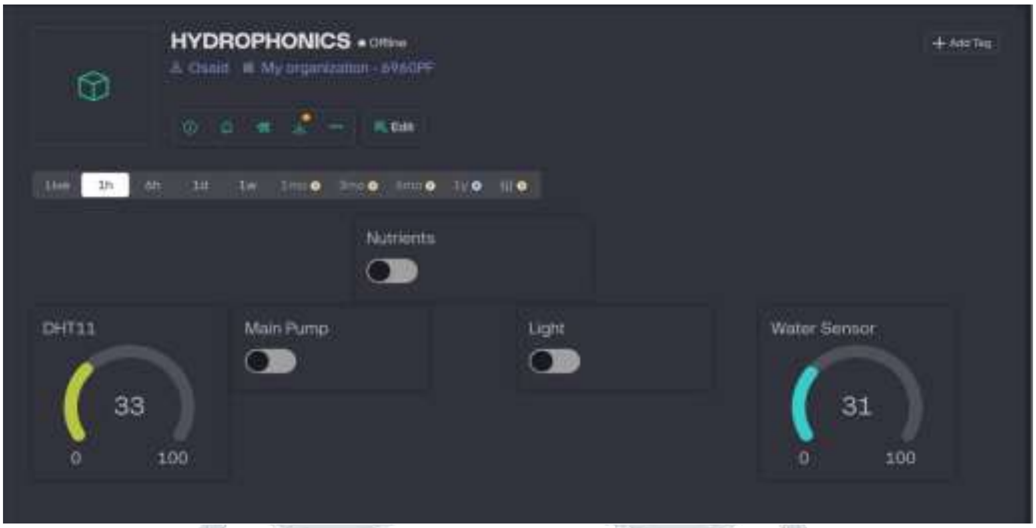

Fig 12 Web Dashboard

7. Conclusions

The integration of IoT technology into hydroponic systems marks a significant leap in modern agriculture, promising enhanced efficiency, precision and sustainability. This system utilizes the Node MCU microcontroller to create an automated hydroponic vertical system that integrates an array of sensors, actuators and modules. The system monitors and effectively manages the parameters to ensure optimal plant growth. Smart Sprout incorporates Wi-Fi capabilities which provides real-time data monitoring and remote control via Blynk IoT. Analyzing the results, it is found that the yield is doubled, nutrient absorption is maximized, The growth rate has seen a significant improvement and the harvest time is reduced to approximately half. Water usage, pest and disease incidences are also minimized. Therefore, it can be concluded that Smart Sprout integrated with IoT provides an efficient and sustainable solution to the challenges faced by conventional farming techniques.

The future of the IoT-based hydroponic system promises transformative advancements that will redefine modern agriculture. The future scope includes Artificial Intelligence (AI) and Machine Learning Integration enabling optimized crop yield and efficiency. Innovative Robotic and Autonomous Systems can be developed to facilitate hydroponic system maintenance and troubleshooting. Advanced User Interfaces by incorporating Augmented Reality (AR) and Virtual Reality (VR) can be developed for immersive hydroponic system management. Nano-sensors and Wireless Sensors can be integrated for detailed plant health monitoring and control.

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