IoT Based Efficient Hydroponics System

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Abstract: Hydroponics is a method of growing plants in water based nutrient solution instead of soil. The key to sustainable agriculture is hydroponic farming, this saves water, land, and resources, gives better yield than conventional method. The integration of IoT in hydroponics improves intelligence, accuracy, and efficiency. The results of IoT based efficient hydroponic system developed for lettuce plant is illustrated in this paper.

1 INTRODUCTION TO HYDROPONICS

Due to rapid increase in population, urbanization, and industrialization the per capita land is decreasing. The soil fertility has reached saturation level, because of this crop yield is not increasing even after the increased application of fertilizers (Ayaz M,2019). The unpredictable weather and climate conditions, rise in temperatures and poor water management are posing menace to food production by conventional method of agriculture (Harikrishna R B,2021).

Hydroponics is a method of growing plants without soil, where plants are grown in nutrient-rich water-based solutions (Palande,2018). In hydroponic systems, plants receive their essential nutrients directly from the water, which is carefully balanced and supplied to the plant roots. The roots are initially grown by an inert growing medium like coconut coir. This soil-less cultivation technique allows for precise control over plant nutrition, water usage, and environmental conditions such as temperature, humidity, and lighting. Hydroponics can be implemented in various setups, including vertical towers, nutrient film technique (NFT) channels, or deep-water culture (DWC) systems (Ramos C,2019). It offers advantages such as efficient resource utilization, faster growth rates, higher crop yields, and the ability to grow plants in areas with limited access to arable land.NFT in hydroponics refers to the Nutrient Film Technique, a hydroponic system where a thin film of nutrient-rich water flows over plant roots. It promotes optimal nutrient uptake and root development, especially for leafy greens and herbs.

The integration of IoT (Internet of Things) technology has revolutionized hydroponics by offering greater control, automation, and efficiency in managing hydroponic systems (Chetan D M,2015). This paper demonstrates the results of IoT based hydroponics systems developed for lettuce plant.

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2 METHODOLOGIES

The methodology followed for the mechanical construction of hydroponics system is explained below.

2.1 Mechanical construction of hydroponics system

Fig 1: Mechanical construction.

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The mechanical construction of an IoT-based NFT (Nutrient Film Technique) hydroponics system typically involves several key components:

1. **Growing/NFT Channels**: The NFT hydroponics system consists of 3 channels with 6 holes each with a distance of 15cm from centre to centre, where the plants are placed. These channels are typically made of food-grade PVC or other suitable materials that are resistant to water and nutrient solutions.
2. **Support Structure**: A sturdy support structure which is made up of supporting rods are connected with the help of the clamp and the rods are made up of galvanized iron. These supporting structure is needed to hold the NFT channels in place. This structure should be able to withstand the weight of the plants, nutrient solution, and other system components.
3. **Pump and Reservoir**: A submersible pump of 14W power which can pump water up to a height of 1.4m is used to circulate the nutrient solution from a reservoir to the top of the NFT channels. The reservoir which can hold up to 30L of nutrient solution, which is continuously recirculated through the system. The pump ensures a steady flow of the nutrient solution over the plant roots.
4. **Return System**: At the end of the channels, a return system collects the excess nutrient solution that has passed through the root zone. This solution is then redirected back to the reservoir with the help of PVC pipes which will be recirculated.
5. **Sensors and Control System**: IoT integration involves the installation of sensors to monitor various parameters such as pH, EC (Electrical Conductivity), temperature, and humidity (Michael G W,2021). These sensors transmit data to a control system, which can be a microcontroller or a central computer. The control system processes the data and triggers appropriate actions, such as adjusting nutrient levels or activating irrigation cycles.
6. **Lighting System**: In indoor or low-light environments, an artificial lighting system (PAR spectrum light) is installed to provide the necessary light intensity and spectrum for optimal plant growth.

The mechanical construction of an IoT-based NFT hydroponics system should prioritize durability, functionality, and ease of maintenance. It is essential to ensure proper sealing, secure connections, and efficient nutrient circulation to create an effective and reliable system.

2.2 Proposed IoT based hydroponics system

IoT sensors enable real-time monitoring of parameters such as water pH, nutrient solution levels, temperature, and humidity, providing instant access to vital information for timely interventions.

Automation and remote-control capabilities allow for tasks such as water pump scheduling and nutrient adjustment based on plant needs, while remote monitoring facilitates system management from anywhere. The data collected by IoT sensors enables data-driven decision-making, optimizing cultivation strategies and effective resource usage.

The Fig.2 shows the block diagram of the IoT based hydroponics system:

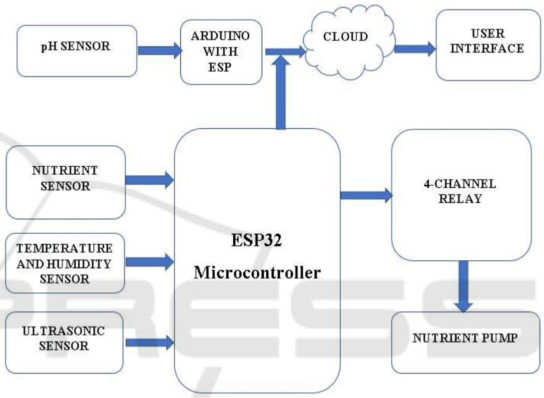


Fig 2: Block diagram of proposed hydroponics system.

ESP32 microcontroller - Used as a microcontroller to store data and also helps the system to connect to Wi-Fi through which monitoring and controlling of sensor values is possible. In this project, data from ultrasonic sensor, EC sensor and temperature and humidity sensor is uploaded to blynk application using esp32 board.

Ultrasonic sensor - Ultrasonic sensors are electronic devices that utilize emitted ultrasonic sound waves to determine the distance to a target, subsequently converting those waves into electrical signals. In this project, it is used to measure water level in the container. As water reaches to a level which is 7cm from the sensor, nutrients will be dispensed into the container.

EC sensor or Nutrient sensor - An EC (Electrical Conductivity) sensor is a device used to measure the electrical conductivity of a solution. EC sensors are commonly used in hydroponics, aquaponics, and other applications where precise monitoring of nutrient levels in water is essential.

pH sensor - A pH sensor is a device used to measure the acidity or alkalinity of a solution by determining its pH value. pH is a measure of the concentration of hydrogen ions (H+) in a solution and indicates the level of acidity or alkalinity on a logarithmic scale from 0 to 14. pH value of 7 is considered neutral, and values less than 7 indicate acidity. Values above 7 indicate alkalinity. In hydroponics, pH sensor is used to measure pH of nutrient solution.

ESP8266 microcontroller - Used as a microcontroller to store data and also helps the system to connect to Wi-Fi through which monitoring and controlling of sensor values is possible. In this project, data from pH sensor is uploaded to blynk application using esp8266 board.

4-Channel relay module - A 4-channel relay module is a device that allows you to control multiple electrical circuits using a microcontroller or other control signal. In this project, this device is used to control nutrient dispenser pumps and pH up and down solutions.

Nutrient pump - Used to dispense nutrients (NPK) into the main container of the hydroponics system. These pumps are also used to dispense pH up-down solutions into the container to balance pH.

Blynk application - Blynk is a popular IoT (Internet of Things) platform that allows us to easily create mobile applications to control and monitor our connected devices. In this project, Blynk application is used to monitor and control nutrient dispensing, pH values, EC values in real time.

Arduino uno - The Arduino Uno is a microcontroller board based on the ATmega328. In this project, Arduino uno is used to store data from pH sensor and transmit the data to esp8266. Since Arduino uno does not have Wi-Fi connecting capability, we use serial communication between Arduino uno and esp8266.

BME280 - The BME280 is a temperature and humidity sensor particularly developed for mobile uses and wearables where size and low power consumption are crucial design parameters.

2.3 Circuit connections of the proposed hydroponics system

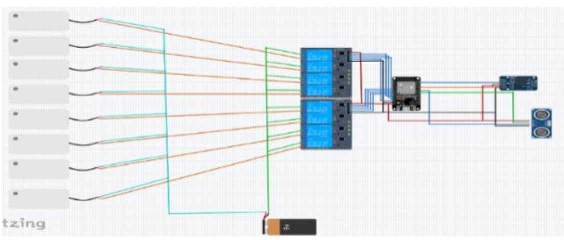


Fig 3: Circuit connection of hydroponics system.

Circuit diagram consists of ESP32 microcontroller and ultrasonic sensor, RTC module and two 4-channel relay modules are connected to esp32 microcontroller. Nutrient dispenser pumps are controlled using relay module. RTC module is used to get real time data which is used to dispense nutrients. Battery is connected in series between pump and relay module.

2.4 Flow chart of control mechanism of IoT based hydroponics system

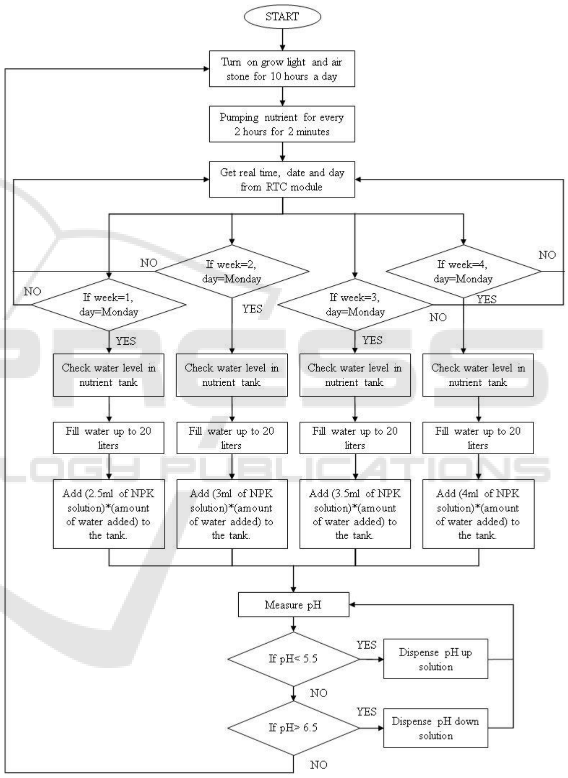


Fig 4: Flow chart of control mechanism proposed hydroponics system.

Lights (PAR Spectrum lights) and air stone are turned on, which will be continuously switched ON for 10 hours per day. These lights are an alternative for sunlight, which helps the plants to grow. Hence both turn on and turn off periods are equally important. Pump the nutrient water from the reservoir to the NFT channel for 2 minutes every 2 hours. This nutrient water forms a thin layer in NFT channel which touches the root of the plants and nutrients is absorbed by these roots which helps in plant growth.

By using RTC module, we get the real time, date, and day. Data from the RTC module is used to dispense nutrients and nutrient requirement will increase week by week as the plant grows. So, it is suggested to increase the nutrient concentration by 0.5ml of NPK every week. After one week, the quantity of nutrient solution decreases in nutrient tank (reservoir), then we add water till it reaches 20 litres in the tank and it is measured by using an ultrasonic sensor. Based on the amount of water added in the tank, we calculate the amount of nutrients (NPK) that has to be dispensed for the present week by using the formula: (amount of water added) * (an increment of 0.5ml of NPK solution that was dispensed in to the tank in previous week). Dispensing of nutrients is achieved by controlling relay modules. Air stone helps in mixing of nutrients with water in the nutrient tank.

After mixing nutrients with water, pH of nutrient solution has to be checked which should be between 5.5 and 6.5 for lettuce plant and when the pH is less than 5.5, pH up solution has to be added which increases the pH values until it maintains the optimum value. Similarly, when pH crosses more than 6.5, pH down solution has to be added which decreases the pH of the solution.

2.5 Control Flow of the proposed hydroponics system

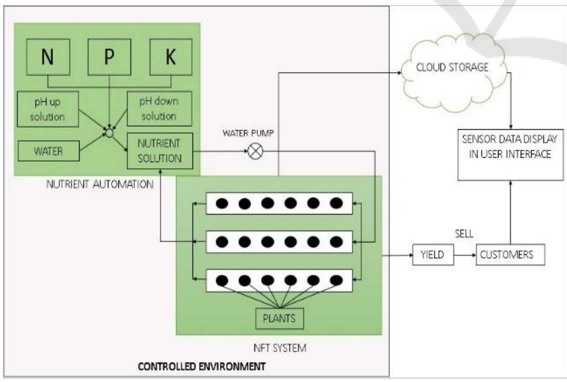


Fig 5: Control flow of hydroponics system.

The control flow of an IoT-based efficient hydroponics system typically involves several components working together to monitor and control various aspects of the hydroponic setup. Here is a general overview of the control flow. The system utilizes various sensors to collect data about environmental conditions such as temperature, humidity, light, pH, and nutrient levels in the hydroponic system. These sensors can be connected to a microcontroller (ESP32, Arduino and ESP8266), which gathers the sensor data. The collected sensor data is then transmitted to a central hub or cloud server using wireless communication protocols such as Wi-Fi, Bluetooth, or cellular networks. This allows for real-time or periodic data updates from the hydroponic system to the cloud. The control actions determined by the users are sent back to the hydroponic system via the IoT device or microcontroller. Actuators such as pumps or relays are used to carry out the control actions. For example, nutrient pumps can be activated to deliver the right amount of nutrients to the plants. The system continuously monitors the effects of the control actions by collecting feedback data from sensors. This feedback data is used to evaluate the impact of the control actions on the hydroponic system's performance. It allows for continuous monitoring and adjustment of the control to ensure optimal plant growth and resource efficiency. The IoT-based hydroponics system often includes a user interface, such as a mobile application in our case Blynk application, that enables users to remotely monitor and control the system. This allows users to access real-time data, receive alerts or notifications, and manually intervene if necessary.

3 ANALYSIS OF DEVELOPED HYDROPONICS SYSTEM

Analysis of the hydroponics system is explained below.

3.1 Data uploading to cloud during specific duration

Data from sensors are uploaded to the cloud (Blynk application) using esp32 microcontroller.

Below table shows the data being uploaded to blynk application for a duration of 5 minutes:

Table 1: Data uploaded from sensors to Blynk application during 9:00am to 9:05am.

Sensors used	Sensor data uploaded from 9:00am to 9:05am					
	9:00 am	9:01 am	9:02 am	9:03 am	9:04 am	9:05 am
Ultrasonic sensor	7.43	7.46	7.44	7.38	7.40	7.44
pH sensor	5.8	5.8	5.9	5.8	5.9	6.0
Temperature sensor	23.6	23.6	23.6	23.5	23.4	23.5

From the above table it is clearly observed that during 5 minutes duration, the data that is uploaded to Blynk application from ultrasonic sensor, pH sensor and temperature sensor are almost constant. Lettuce plant requires an optimum temperature of 18-24°C and from the table we can see that temperature sensor is reading temperature which is within the optimum range. The optimum pH range of lettuce plant is between 5.5-6.5 and from the table we can verify that the pH is within the optimum range. Ultrasonic sensor is used to detect nutrient water level in the container.

3.2 Comparison of lettuce plant growth in soil-based agriculture and hydroponics

Lettuce plant can grow in both soil- based (conventional) agriculture and hydroponics and below table represents few significant difference among these methods.

Table 2: comparison of lettuce plant growth in soil and hydroponics.

Aspect	Conventional Growing	Hydroponic Growing
Growing Medium	Soil	Nutrient Solution
Water Usage	High	Low
Nutrient Management	Soil-based fertilizers	Precise nutrient control
Space Requirement	Large	Small
Pest Control	Pesticides	Controlled environment
Harvest Time	Longer	Shorter
Yield	Moderate	High
Days to Harvest	60-70 days	25-35 days
Environmental Impact	Soil erosion, nutrient runoff	Reduced water usage, less soil degradation
Seasonal Limitations	Outdoor growing may be seasonal	Year-round cultivation possible
Temperature Range	16-24°C (60-75°F)	18-24°C (65-75°F)
Light Source Wavelength	Natural sunlight	LED grow lights with optimized wavelength

4 RESULTS

The results of the plant growth is explained in the below sections

4.1 Results of plant growth

Duration of green leaf lettuce is between 6 to 8 weeks after its germination. Below pictures shows the growth of lettuce plants once they are transferred to NFT system.

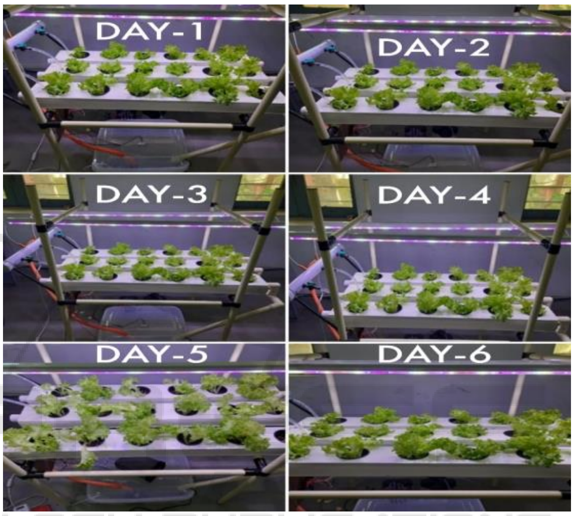


Fig 6: Lettuce plants growth in 1 week duration.

4.2 Results of pH sensor

The optimum pH level for lettuce to grow in hydroponics system is between 5.5 to 6.5 which is slightly acidic in nature. Below picture shows the pH output in serial monitor of Arduino IDE.

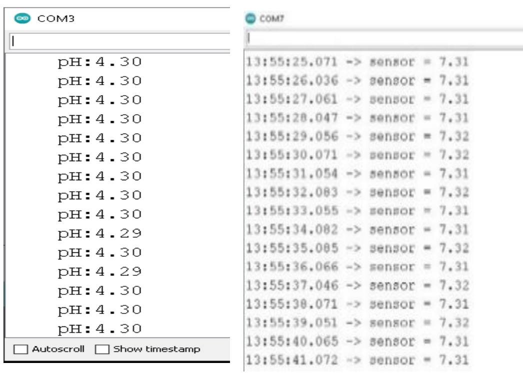


Fig 7: pH output for acid (left), pH output of distilled water (right)

4.3 Results for nutrient dispensing

To automate nutrient dispensing in hydroponics, a 4-channel relay and a RTC module is used and 2ml of NPK has to be dispensed in 1 Liter of water once a week. The below picture shows dispensing of nutrients by controlling relay channels.

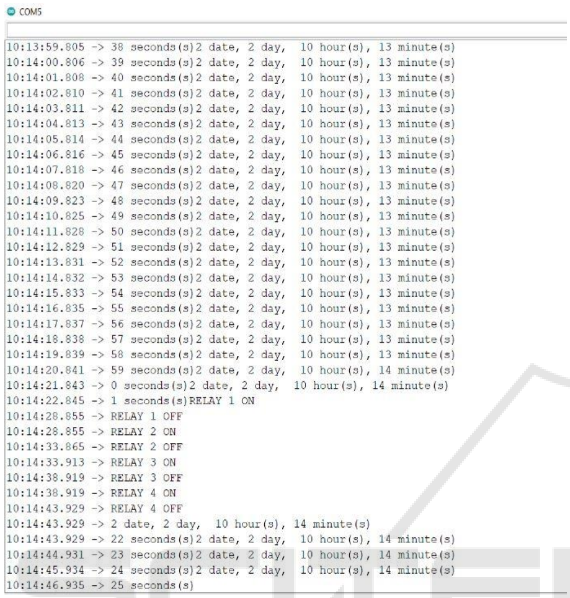


Fig 8: Nutrient dispensing using 4-channel relay and RTC module

4.4 Results of Blynk Application

Data from the sensors and nutrient dispenser is uploaded to a user interface called Blynk application. Below pictures shows the Blynk application templates and controller for nutrient dispenser. Nutrients can also be manually dispensed using Blynk app and user can dispense NPK solutions along with pH up- down solutions manually based on the requirements.

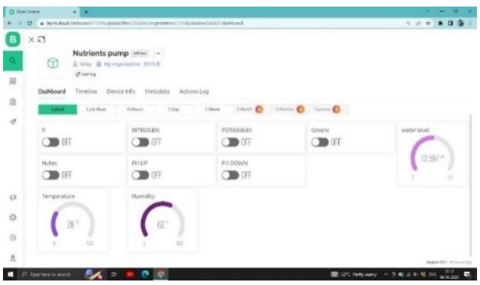
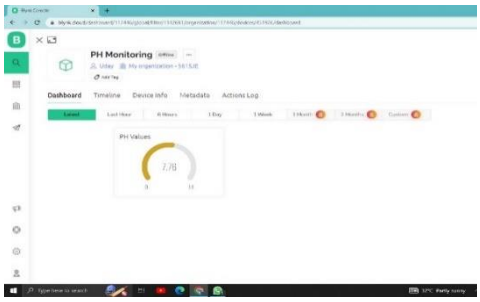


Fig 9: Nutrient pump template in Blynk application.



. Fig 10: pH monitoring template in Blynk application

5 CONCLUSION

The advantages of hydroponics are making it more popular over soil-based cultivation. However, integrating IoT technology into hydroponics enhances the efficiency, precision, and scalability of cultivation. The results of the IoT based hydroponics system developed for Lettuce plant has been presented here by harnessing the power of sensors, connectivity, and data analytics, growers can optimize resource usage, minimize manual intervention, and achieve higher yields of quality yield. This combination of hydroponics and IoT holds tremendous potential for sustainable and future-forward agriculture practices.

The future scope of IoT-based efficient hydroponics systems is promising and holds potential for significant advancements in sustainable agriculture. IoT technologies can further enhance automation in hydroponics systems. Integration with AI algorithms and machine learning can enable predictive analysis, optimizing resource allocation, and decision-making. Advanced data analytics and predictive models can be developed to analyse large-scale data collected from IoT sensors. IoT-based hydroponics systems can integrate with other precision farming technologies such as drones, robots, and hyperspectral imaging. This integration can enable automated plant monitoring, targeted nutrient delivery, and precision harvesting techniques, further enhancing efficiency and productivity.

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