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Intelligent Hydroponics: IoT Integration for Nutrient Analysis and Automation

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Abstract: The paper introduces an innovative hydroponics system integrating IoT technology to achieve advanced nutrient optimization and automation. Hydroponics is well recognized for its water efficiency, with its ability to use significantly less water compared to traditional soil-based farming methods. Hydroponics is a sustainable solution in areas where water is scarce since its closed-loop systems can use a lot less water than conventional soil-based agriculture. Plants may suffer from pests and diseases that are present in the soil. These dangers are diminished by hydroponics, which facilitates better plant health maintenance. A recent development in agriculture is hydroponics, which uses water as a planting medium rather than soil. The term "hydroponic nutrition" or "nutrient solution" refers to the process of using fertilizer in a hydroponic system by mixing it with water. The concentration of nutrients in the solution, which is then reflected by the electrical conductivity (EC), has a significant impact on crop productivity. The fertilizer and water are often combined in the proper ratio to manually mix the nutritional concentration. Today, soil-based agriculture faces challenges from a variety of man-made factors, including urbanization and industrialization. The decrease of soil fertility and quality is also a result of uncontrolled chemical usage in agriculture, abrupt natural disasters, and climate change. Because of this, researchers have created a brand-new alternative farming method known as soil-less agriculture. The technique of hydroponics involves growing plants without soil in water with a mineral solution. Urban agriculture, or hydroponics, is a modern form of agriculture. This project illustrates a hydroponic system with integrated numerous sensors, including a TDS meter, pH sensors, and a DS18b20 temperature sensor. The proposed method provides remote monitoring by uploading data to the cloud. The nutrient analysis is carried out and based on the analysis automated addition of nutrient solution is done, providing smart nutrient management in hydroponics system. The proposed system outperforms the existing ones in terms of compatibility, cost effectiveness, less manpower, faster growth, and better yield.

Keywords: Hydroponic, soil-less farming, nutrient rich water, cocopeat, clay, pellets, ESP32, sensors.

1. Introduction

Approximately 18% of the GDP and 43% of the country's land are devoted to agriculture, which is regarded as the foundation of the Indian economy. By 2050, there will be 9.8 billion people on the planet due to the rapid population growth, with developing countries like India expected to bear the brunt of this. Since agriculture is the main source of food, it necessitates significant technological advancement. Thus, it is crucial to maximize agriculture's economic potential. Taking good care of your plants is essential to maintaining their health and appearance. Watering, rejuvenation, fertilizer, and other things are just a few of the various components of plant maintenance. There are a wide variety of plant species that require distinct treatments, all of which are typically applied by hand. Water continues to be the primary source of life for all plants, despite the wide variety of plant kinds, as it facilitates the process of photosynthesis. The word hydroponics comes from the root's "hydro", meaning water, and "ponos", meaning labour, this method of growing plants which does not use soil. Hydroponic systems ensure that plants have easy access to water, oxygen, and all the nutrients they need to thrive by delivering nutrients directly to the roots of the plants, doing away with the requirement for traditional soil-based farming. Hydroponic plants that are dependent on water for their nourishment. Numerous plants, including fruits, vegetables, herbs, and certain flowers, can be grown hydroponically. It's a flexible and environmentally friendly method of farming. Plants produced in hydroponic systems are usually grown in a controlled environment, which might be an indoor facility, a greenhouse, or sometimes even outside. Planting material used in hydroponics includes sponge, coconut, and other varieties of coconut powder. When caring for plants hydroponically, it is crucial to schedule the addition of water and replacement of fertilizers. It would also be highly practical if the plant owner had an IoT-enabled hydroponics system. An automated watering system for hydroponically grown plants is now a real possibility thanks to technological advancements, particularly in the areas of microcontrollers and wireless systems. The agriculture sector needs to undergo a revolution to become more intelligent and convenient considering the new needs of today. In order to close the gap between agriculture and the Internet of Things, this project combines cutting-edge technology, which will support resource-efficient and sustainable farming methods. The following sections delve into the intricate details of the system's architecture, sensor integration, data analytics, and user interface, showcasing a comprehensive approach towards modernizing hydroponic cultivation.

2. Related Papers

Providing for food demands is one of the primary problems facing human society [1]. The United Nations Food and Agriculture Organization (FAO) projects that there will be 9.1 billion people on Earth by the year 2050. This means that in order to feed the 9.1 billion people that live on Earth today, food production must increase by 70% between 2005 and 2050. By 2030, 60% of people on Earth are expected to live in cities, according to UN predictions. This will result in a decrease in agricultural land and an increase in the city's metropolitan area. However, as technology in the field of information technology advances, new technologies such as the Internet of Things (IoT) emerge. The design, development, and execution of our initial research on the smart hydroponic system—which connects to the cloud server via the Internet of Things—are presented in this paper.

The work [2] details the creation of a system that is entirely controlled by software developed in a lab. Throughout the whole production cycle, it continuously measures the pH and conductivity every 24 hours. Additionally, it enables automatic adjustment of any variance through the use of solenoid valves that supply nutritional or acid/base solutions. The effectiveness of the suggested equipment was assessed concurrently by cultivating the same variety of lettuce in two distinct methods: hydroponically in a greenhouse managed by the devised apparatuses, and conventionally in soil, which was used as a reference. Similar to the data obtained by the aforementioned researchers, the data sequence for the automated hydroponic system's nutrient content was K > N > Ca > P > Mg > S > Fe > Zn > Mn > Cu. This resemblance demonstrates how well the conductivity and pH parameters can be controlled in the hydroponic system, providing the producer with a practical and efficient substitute for growing lettuce.

A contemporary method [3] of cultivating plants is called "smart hydroponics farming," which uses water rich in nutrients rather than soil. With the help of a hydroponic system called Nutrient Film Technology, plants can optionally absorb oxygen and nutrients by developing a thin layer of nutrient-rich water around their roots. The types of lettuce that are ideal for hydroponic growing and can flourish under NFT. With smart hydroponics, farmers can now monitor any changes in the plant, root zone, and environment thanks to automation, robotics, and the Internet of Things. The study's findings are included into the design of microcontroller-based real-time operating systems. A promising technique for growing environmentally friendly, superior lettuce in urban areas and other locations where traditional agriculture is challenging or unsustainable is hydroponic smart lettuce. Robotics, deep neural network-based fault detection in hydroponic lettuce plantations, automated drip irrigation in conjunction with hydroponic systems, automation systems based on expert systems, automated Smart hydroponics nutrition plant systems, and intelligent hydroponic management and monitoring systems are some of the additional technologies utilized in hydroponic systems. The simulation results obtained on an IoT-based base environment reveal higher performance.

Hydroponic agriculture is a solution to the shortage of arable land, which may result in a decrease in agricultural output capacity [4]. The maintenance of pH levels in accordance with the plants presents a problem in hydroponics. We have created the Internet of Things (IoT), a technology that enables routine monitoring of all aspects, to address this problem. We can simply monitor, control, and make sure that all necessary values are maintained in the hydroponic system with the help of the Internet of Things. It is possible to apply variables like the pH level, moisture, temperature, level of water, and intensity of light by connecting actuators and sensors to the micro-controllers (ESP32). A smartphone app is used to control the actuators, and the sensor data is kept on the Thing Speak cloud. The maintenance and automated observation are carried out by the IoT, which is utilized to transmit and retrieve information to the internet.

The paper [5] describes the design and implementation of an internet-of-things-based automated smart hydroponics system. The world's growing food demand and the necessity for new, sustainable farming techniques that leverage the Internet of Things are the problems that this system must address the concept was built using NodeMcu device, Node Red, MQTT, and devices that were chosen during component selection based on relevant parameters. The cloud was used to analyse and monitor the data. The Internet of Things, hydroponic systems, and a review of previous studies were all looked at. Apart from constructing, coding, and evaluating the prototype, sensor information from two different sites was gathered and monitored via a mobile app and cloud-based website. In addition, a bot has been added to manage the supply network and send out notifications. The system enhanced its functionality and enabled it to effectively accomplish the goal of the system's implementation as a whole

The design and implementation of iPONICS [6], an intelligent, inexpensive Internet of Things-based control and monitoring system for hydroponic greenhouses, are presented in this work. The system is based on three different types of sensor nodes. In addition to managing the pump and keeping an eye on the water quality in the greenhouse, the main (master) node also gathers and transmits data from the slave nodes. Slave environment sensors keep an eye on the greenhouse's environmental conditions and relay the information to the main node. Activity (movement in the region) is monitored by security nodes. The system keeps an eye on the temperature, humidity, and water quality in the greenhouse to make sure crops are grown in the best possible conditions in accordance with hydroponics requirements. By connecting to a website and monitoring these parameters, greenhouse caretakers can monitor them remotely. A new fuzzy inference system determines the duration of plant irrigation. The technology is designed to use minimal power in order to make off-grid operating easier.

The dramatic decrease [7] in arable land and the rapid advancement of hydroponic system technologies such as Nutrient Film Technique (NFT) have left farmers facing immense hurdles. Special consideration must be given to a number of aspects in this hydroponic system, including the water's temperature, level, acidity (pH), and nutrient content (EC/PPM). We initially keep an eye on NFT Hydroponic farmers and gather their data before methodically analysing and assessing them. Regretfully, the conventional method (human) is still used to control it. For instance, regulating the concentrations of nutrients requires daily attention, resulting in significant time wastage. We require a readily deployed and utilized approach to tackle these problems. Using the idea of the Internet of Things, we developed a hydroponic automation and monitoring system that can be observed through sensors linked to the Arduino Uno microcontroller, the ESP8266 Wi-Fi module, and the Raspberry Pi 2 Model B microcomputers as the webserver. This makes it possible for any hydroponic farming block to speak with the webserver (broker). Through the online interface, the user can monitor and control the NFT hydroponic farming system. The NFT hydroponic web interface management systems make use of JavaScript, jQuery, and Bootstrap, which are responsive web frameworks for the front end. The outcome demonstrates how this method aids farmers in increasing the efficacy and controlling NFT Hydroponic Farm efficiency of NFT monitoring and control

The main obstacle facing open field/soil-based agriculture since the dawn of civilization is the decline in the [8] amount of land available per person. With 3 billion people on the planet in 1960, per capita land was 0.5 hectares; by the year 2050, that number will have dropped to 0.16 ha from 0.25 ha due to the presence of 6 billion people. Arable land under agriculture is expected to decline further as a result of the world's fastest-paced urbanization, industrialization, and iceberg melting (a clear consequence of global warming). Again, the saturation point of soil fertility has been reached, and production gains cannot be sustained by adding more fertilizer. Factors like low soil fertility in some cultivable areas, decreased chance of natural soil fertility build-up by microbes due to persistent farming, regular periods of drought, unpredictable climate and weather patterns, temperature rise, pollution in rivers, inadequate water management and massive water waste, decline in ground water level, etc. pose a threat to food production under conventional soil-based agriculture. This study set out to ascertain the impact of several parameters on the training and research viability of hydroponic agriculture. Using the census method, 176 experts in the Agricultural Ministry made up the research population. This study was conducted using a descriptive-correlation methodology. A panel of specialists made up of senior professors and research committee advisers determined the validity of the instrument.

[9] Hydroponic farming is a vital component of conventional farming, as it involves growing plants without the use of soil. Specifically, farming is dependent on the environment. A new technology called hydroponics farming enables farmers to better utilize their property without the need for soil. especially in unsuitable settings and locales. Preserving water, raising agricultural yields, reducing the negative effects of pesticides and other elements that deteriorate soil quality, and protecting the land are its main objectives. It is the hydroponics system's economical implementation for small farms.

[10] The technique for cultivating plants without soil by using a rich in nutrients water solution is known as hydroponics. The fluid submerges the roots of the plants, providing them with all the nutrients they need to flourish. Water serves as the primary growing medium in all hydroponic systems. The limitation of a greenhouse setting is the requirement to uphold particular levels of humidity, pressure, and temperature. In hydroponics, maintaining the monitoring of pH and electrical conductivity is another challenging task. Using the Internet of Things, this system automatically checks and modifies parameters, provides required resources, and uploads data to a cloud server. Users will be able to quickly monitor and maintain their mobile devices by using an application that provides them with the current state.

3. Methodology

The sensor in the automated hydroponic system aids in the transfer and retrieval of data by detecting the state of the developing plant. The hydroponic system relies heavily on the Internet of Things (IOT), where sensors and actuators are utilized to automate the system. The sensor gathers data and transmits it to the cloud base, where the user can access plant condition information. In the hydroponic system, the temperature sensor, pump, Arduino Uno, and Esp8266 are the primary components. In line with this, actuator integration includes pumps and valves to enable real-time modifications based on sensor data. Secure connection is guaranteed by the integration of IoT-enabled devices, while data processing, analysis, and storage are handled by a cloud-based platform. Relevant insights are extracted by data analytics algorithms, and practical suggestions for optimal crop growth are given by decision support systems. Remote monitoring and control are made easier by an intuitive user interface that includes warnings and graphical displays of data patterns to help with decision-making. In order to ensure a reliable and effective Smart Hydroponic System deployment, the process is completed with energy efficiency considerations, extensive testing, and documenting of system specifications.

3.1 Flow Chart:

Fig 1 shows the flow chart. First, the intelligent hydroponic system initializes every component to ensure it is ready for use. Next, it determines whether the sensors and main unit can interact. If an issue arises, it tries once again until it succeeds. Subsequently, the system collects information from sensors that gauge the water's pH, temperature, and nutrient content. Thing Speak is an online platform that receives this data. There, it is transformed into graphs that display the variations in these factors across time. The system modifies the nutrient mixture for the plants based on this data to make sure they're getting what they need. The flowchart then directs attention to developing data analytics and decision support tools, followed by the creation of a user-friendly interface for remote monitoring and control. Iterative design processes are demonstrated by the integration of energy efficiency considerations prior to testing. Before reaching the "End," the flowchart finally finishes with a documentation step that clarifies the system design, specs, and maintenance guidelines.

Fig 2 depicts the block diagram. The block diagram for the design and implementation of a Smart Hydroponic System using IoT offers a comprehensive snapshot of the system's architecture and functional components. IoT devices, such as sensors and actuators, which are in charge of data gathering and control mechanisms, are at the centre of it all. As the brains of the system, the central control unit processes sensor data and sends actuator commands. Robust communication protocols provide smooth connection between IoT devices and the central control unit. Scalable and safe administration is made possible by the cloud platform, which acts as an essential backbone for data processing, analysis, and storage. Farmers are empowered with remote monitoring and control capabilities using an intuitive interface, as illustrated in the diagram, which offers insights through graphical representations and warnings. The interconnected components powering the Smart Hydroponic System's sustainability and efficiency through the Internet of Things are captured in this block diagram.

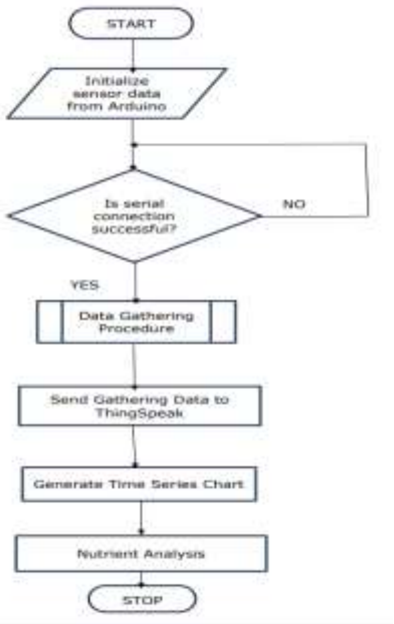

Fig 1: Flow Chart

3.2 Block Diagram:

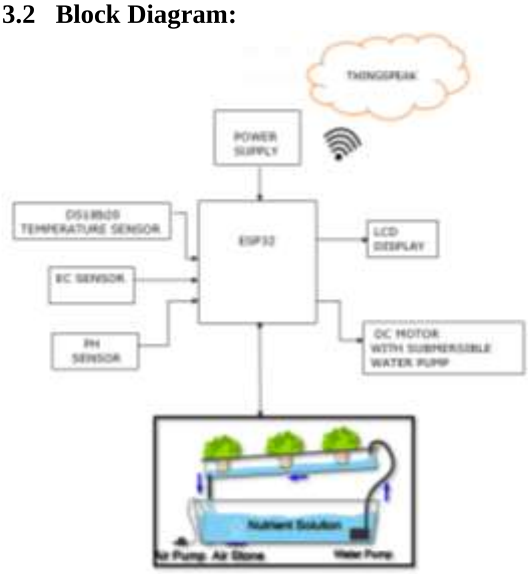

Fig 2: Block Diagram

3.3 Hardware Components:

ESP32: A line of low-cost, low-power system-on-a-chip microcontrollers featuring dual-mode Bluetooth and integrated Wi-Fi is called ESP32. The ESP32 series incorporates built-in antenna switches, RF balun, power amplifier, low-noise receive amplifier, filters, and power-management modules. It uses either a Tensilica Xtensa LX6 microprocessor in both dual-core and single-core variations, Xtensa LX7 dual-core microprocessor, or a single-core RISC-V microprocessor. The Shanghai-based Chinese business Espressif Systems designed and developed ESP32, which is produced by TSMC utilizing their 40 nm technology.[2] It is the ESP8266, Fig 3 microcontroller's replacement.

Fig 3: ESP32

DS18b20 Temperature Sensor: Fig 4 represents a model of DS18b20 temperature Sensor. The miniature temperature sensor DS18B20 has a built-in 12-bit ADC. It is simple to connect to a digital input on a board powered by Arduino. The sensor requires a couple additional elements and communicates via a single-wire bus. The sensors have been described as having an accuracy of +/- 0.5 degrees Celsius and operate between -10 and +85 degrees Celsius. The sensor has two modes of execution: parasitical and normal. A three-wire connection must be installed in standard mode. The data line provides the sensor's power when it is operating in parasitic mode. There are just two cables needed: ground and data.

Fig 4: DS18b20 Temperature Sensor

E201-BNC pH Electrode: Fig 5 represents a model of E201-BNC pH Electrode. Nutrient solutions are employed in hydroponic systems, and the pH scale is used to measure the pH precisely in the nutrient solution. The sensor has an accuracy of about 0.1 pH and can detect pH levels between 0 and 14. The pH of the nutrition solution is kept in the range that plants need, which is between 6.5 and 7. Growers may identify pH problems early on with the use of pH sensors, which promotes healthier plants and greater crop yields.

Fig 5: E201-BNC pH Electrode

TDS sensor: Fig 6. represents a model of TDS sensor.

Parameter	Value
Input voltage	3.3V / 5V
Output Voltage	0 ~ 2.3V
Working Current	3 ~ 6 mA
TDS Measurement Range	0 ~ 1000ppm

Fig 6: TDS sensor

I2C: Inter-Integrated circuit is referred to as I2C. It is also known by the acronyms IIC and I2C, Fig 7. Short-distance communication is frequently accomplished using the serial I2C protocol. The two wires that make up the I2C protocol, SDA and SCL, are used for bidirectional synchronous serial bus communication. Because I2C Protocol requires two wires for communication, it is also very inexpensive. As a result, it is the most widely used Serial Bus across a wide range of applications, including consumer electronics, industrial equipment, automotive, aerospace, and the Internet of Things.

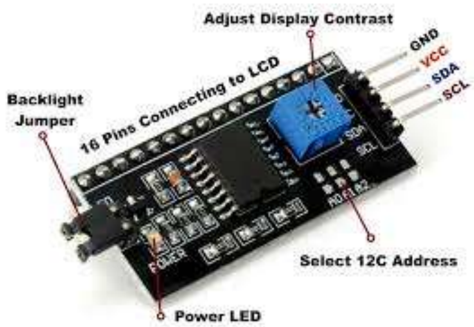

Fig 7: I2C

LCD – 16x2: The term LCD (Fig 8) stands for liquid crystal display. It is one kind of electronic display module used in an extensive range of applications like various circuits & devices like mobile phones, calculators, computers, TV sets, etc. These displays are mainly preferred for multi-segment light-emitting diodes and seven segments. The main benefits of using this module are inexpensive; simply programmable, animations, and there are no limitations for displaying custom characters, special and even animations, etc. The operating voltage of this LCD is 4.7V-5.3V. It includes two rows where each row can produce 16-characters. The utilization of current is 1mA with no backlight.

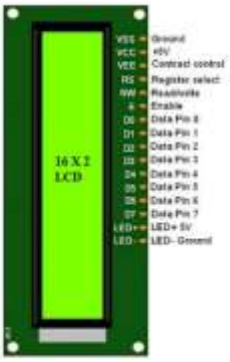

Fig 8: 16x2 LCD

3.4 Software Components:

Arduino IDE: Writing and uploading code to the Arduino boards, Fig.9 is done via the open-source Arduino IDE software. Integrated Development Environment is referred to as IDE. illustrating is an expression frequently used to describe programmed or code generated using the Arduino IDE. The sketch is saved as a document with the.ino extension. To upload the sketch built with the Arduino IDE software, we need to link the Arduino board and Genuino to the IDE.

Fig 9: Arduino IDE

4. Other Applications

1. Precision Agriculture:
Precision agriculture is made possible by the integration of IoT with hydroponics, which allows for continuous monitoring and control of important parameters which comprises pH, fertiliser levels, and ambient conditions. Crop growth and resource use are thereby optimised.

2. Resource Efficiency:
By precisely tailoring the growing environment based on data-driven insights, the smart hydroponic system minimizes resource wastage. This includes efficient water usage, reduced nutrient runoff, and optimized energy consumption, contributing to sustainability.

3. Remote Monitoring and Control:
Farmers can remotely monitor and control the hydroponic system through web or mobile applications. This allows for flexibility in management, enabling timely interventions and adjustments, regardless of the physical location of the farm.

4. Data-Driven Decision Making:
Farmers can take advantage of the system's data analytics capabilities to gain practical insights into crop conditions and growth trends. Crop productivity and quality are improved by making educated choices based on data that is updated constantly.

5. Customization for Crop Varieties:
The smart hydroponic system can be tailored to suit the specific requirements of different plant varieties. This adaptability ensures optimal conditions for diverse crops, promoting versatility in cultivation.

6. Scalability:
The modular design of the system allows for scalability, accommodating the expansion of cultivation areas or the integration of additional sensors as needed. This scalability supports the evolving needs of farmers and facilitates the growth of agricultural operations.

7. Energy-Efficient Practices:
Incorporating energy-efficient components and scheduling mechanisms contributes to sustainable farming practices. The system's ability to optimize energy consumption aligns with eco-friendly initiatives in agriculture.

8. Environmental Monitoring:
Beyond crop cultivation, the system can be extended for environmental monitoring purposes, assessing factors such as air quality and climate conditions. This broader application supports a holistic approach to sustainable farming practices.

5. Results

The following results are obtained after the settup is made and sensor values are measured. Fig 10 represents the initial stage of plant growth. The seeds are sown in the cocopeat until they become a sapling. Fig 11 reepresents the connection between each sensors and ESP32.

Fig 10: Plants Growing Stage

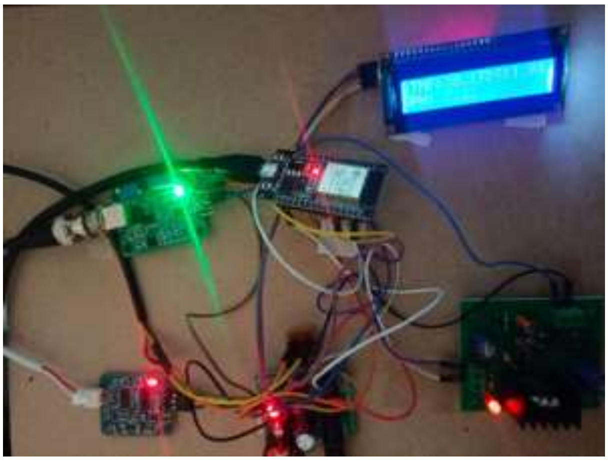

Fig 11: Sensors Connection with the Output Values

Fig 12: Sensors Value in LCD

Fig 13: Temperature Sensor Values in ThinkSpeak

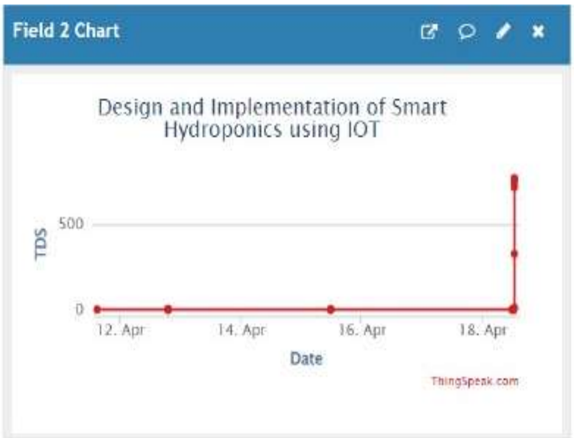

Fig 14: TDS sensor values in ThinkSpeak

Fig 12 represents the values from the sensors displayed in LCD. Fig 13 represents temperature sensor values in ThingSpeak refer to the data collected by temperature sensors and uploaded to the ThingSpeak platform for storage, visualization, and analysis. The values are taken at different time and for different solutions. Fig 14 represents TDS (Total Dissolved Solids) sensor values in ThingSpeak refer to the data collected by TDS sensors and uploaded to the ThingSpeak platform for storage, visualization, and analysis. The values are taken at different time and for different solutions. Fig 15 represents pH sensor values in ThingSpeak refer to the data collected by pH sensors and uploaded to the ThingSpeak platform for storage, visualization, and analysis. The values are taken at different time and for different solutions.

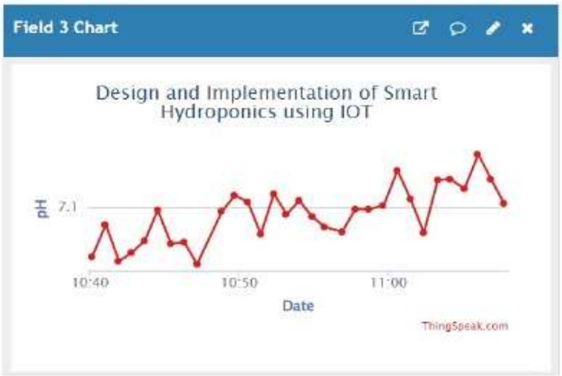

Fig 15: pH Sensor Values in ThinkSpeak

6. Conclusion

This proposed framework represents a pioneering leap in modern agriculture, amalgamating cutting-edge technology with sustainable farming practices. By seamlessly integrating sensors, actuators, and IoT-enabled devices, this system offers unparalleled precision in monitoring and controlling key environmental factors, pH, and nutrition levels, among other. The real-time data analytics and decision support tools empower farmers with actionable insights, fostering informed decision-making for optimized crop growth.

The remote monitoring and control capabilities, coupled with a user-friendly interface, redefine the way farmers interact with their cultivation environments, providing flexibility and adaptability to changing conditions. The scalability of the system accommodates the evolving needs of farmers and supports the expansion of agricultural operations. Beyond efficiency gains, the Smart Hydroponic System contributes to resource conservation, minimizing water and nutrient wastage. Its energy-efficient practices align with sustainable agricultural initiatives, promoting environmentally conscious farming. In essence, the implementation of a Smart Hydroponic System using IoT not only addresses the challenges of contemporary farming but also propels agriculture into a new era of innovation and sustainability. This transformative technology holds the promise of enhancing crop yields, conserving resources, and ultimately reshaping the landscape of agriculture for a more efficient and resilient future.

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