Autonomous Sensor Technology in Hydroponics for Monitoring and Controlling Plant Growth

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Abstract—Today, India wants to be fitter and this health consciousness drives for healthier food. Vegetables available in urban India are usually highly contaminated with pesticides wrecking our health and the cultivating land instead. Organic Farming as an alternative is not very feasible due to its exorbitant prices. Hydroponics along with our designed system offers a new way of cultivation which promotes all aspects of sustainable agriculture thereby providing an alternative to organic farming. In this paper, we have designed a hydroponic system which ensures higher growth rate with controlled environment. The main function of our hydroponic system is to monitor and to control parameters with the help of actuators present in the system to produce plants at a faster rate and focus on inducing the nutrients and minerals into the water system which in turn transports them to the roots. This project aims to bring Autonomous Sensor Technology in Hydroponics to monitor and control growth of plants. This process is executed systematically through the use of internet of thing (IoT) technology. Using NODEMCU (ESP8266), it manages to maintain an optimum condition for nutrient consumed by the plant. This offers advantage for the user to monitor and control the system with less effort and requires no presence at the farmed area. The proposed system uses data in real time to influence the active and counteractive steps.

I. INTRODUCTION

Agriculture is a time consuming and labor demanding sector. The introduction of automation to the field of agriculture is the best solution to these problems and it makes farming in a systematic manner which yields to a higher rate of production. Through this automated method, greater productivity can be achieved in less time. India record of progress in agriculture over the past four decades has been quite impressive. The agriculture sector has been successful in keeping pace with rising demand for food. Contribution of agricultural growth to overall progress has been widespread. Increased productivity has helped to feed the poor, enhanced farm income and provided opportunities for both direct and indirect employment. The success of India's agriculture is attributed to a series of steps. The major sources of agricultural growth during this period were the spread of modern crop varieties, intensification of input use and investments leading to expansion in the irrigated area. In areas where Green Revolution technologies had major impact, growth has now slowed. New technologies are needed to push out yield frontiers, utilize inputs more efficiently and diversify to more sustainable and higher value cropping patterns. At the same time there is urgency to better exploit potential of rain fed and other less endowed areas. Given the wide range of agro-ecological setting and producers. Indian agriculture is faced with a great diversity of needs, opportunities and prospects. Future growth needs to be more rapid, more widely distributed and better targeted. These challenges have profound implications for the way farmers problems are conceived, researched and transferred to the farmers. On the one hand agricultural research will increasingly be required to address location specific problems facing the communities on the other the systems will have to position themselves in an increasingly competitive environment to generate and adopt cutting edge technologies to bear upon the solutions facing a vast majority of resource poor farmers. Agriculture comes from two Latin words: Ager which means a field. Culturia which means cultivation, Due to traditional methods of agricultural process the Indian farmer faces many problems about productivity of agricultural product than others. The advancement in the field of automation is growing progressively in this era, thus it is the necessity to utilize these technologies for human benefit. Here this proposed work is done to provide better results in the field of agriculture. The introduction of these technologies can solve problems due to the unavailability of labour, land space and the increased labour cost.

II. LITERATURE SURVEY

[1] Komal, Kuldeep Bhardwaj, and Mr Kuldeep Bhardwaj. "Implementation of Controlled Hydroponics in Urban Infrastructure." IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) Volume 11 (5) 2014.
In this research, the implementation of controlled hydroponics is described over the roof of high rising buildings as these spaces are not used for any of commercial activity and easy to sustain the growth of hydroponics plant. Microcontroller AT89S52, Temperature and Humidity sensor, Nutrient level and Nutrient flow controller and LDR sensor is used and a program using C language is developed. Implementation of controlled hydroponics in urban infrastructure

III. METHODOLOGY

Autonomous sensor technology in hydroponics involves integrating various sensors, such as pH, temperature, humidity, light intensity, and nutrient sensors, into the system to continuously monitor plant growth conditions. These sensors collect real-time data, which is then transmitted to a central controller, often based on microcontrollers like the ESP8266, for processing. The system uses this data to automatically adjust environmental factors such as pH levels, nutrient concentration, water flow, and light intensity, ensuring optimal growth conditions. IoT connectivity allows remote monitoring and management through cloud platforms like AWS, enabling farmers to receive real-time insights and alerts. By reducing manual intervention and ensuring precise control, this methodology improves efficiency, reduces resource waste, and enhances plant health.

IV. SYSTEM ARCHITECTURE AND METHODOLOGY

A. Components Used

B. [1] User sensor The sensor module for the "Autonomous Sensor Technology in Hydroponics" project includes several key sensors to monitor environmental and water conditions critical for plant growth. The temperature sensor monitors both water and air temperatures. Water level sensor checks the water level and tells that whether it is high or low for plant growth. A humidity sensor keeps track of moisture levels in the air to prevent stress on the plants. These sensors are connected to a microcontroller, which processes data and triggers automated control systems, maintaining an optimal growing environment.

C. Control Module: The control module for the "Autonomous Sensor Technology in Hydroponics" project is responsible for processing sensor data and managing system responses. It consists of a microcontroller (like Arduino or Raspberry Pi) that receives input from various sensors, including pH, EC, temperature, humidity, and dissolved oxygen. Based on predefined thresholds, the microcontroller triggers actuators such as water pumps, solenoid valves, and grow lights to adjust environmental conditions. Additionally, it ensures real-time monitoring and control through a user interface (mobile app or web dashboard). The system also integrates cloud-based data storage for historical analysis and optimization. This closed-loop system enhances automation, reducing manual intervention.

D. Communication Module: The communication module for the "Autonomous Sensor Technology in Hydroponics" project facilitates data transfer and remote control of the system. It uses Wi-Fi for local communication, enabling real-time data transmission between the sensors, microcontroller, and the cloud. For areas with limited Wi-Fi connectivity, LoRa or Bluetooth can be integrated for long- range or local communication, respectively. Data from the sensors is sent to the cloud for storage and analysis, and the user interface (mobile app or web dashboard) allows users to monitor and adjust system parameters remotely. This communication setup ensures seamless operation and accessibility, regardless of location.

E. User Interface Module: The user interface module for the "Autonomous Sensor Technology in Hydroponics" project provides an intuitive platform for monitoring and controlling the hydroponic system. It can be accessed through a mobile app or web dashboard, offering real-time data visualization from the sensors, such as pH, temperature, EC, and dissolved oxygen levels. Users can view system status, historical trends, and receive alerts for any abnormal conditions. The interface also allows users to remotely adjust settings like water flow, light intensity, and nutrient levels. By integrating with the control module, it enables seamless interaction and automation of plant growth management.

[1] very effective and a unique way to succeed the both of the basic goals of attaining food security and environmental protection as the system enables agriculture even in those areas where there is no soil available such as deserts, polar regions, waste lands and constructed areas such as house, apartments etc. It all shows that the controlled hydroponics system serves as the futuristic smart cultivation technique and save the future of mankind [2] Adh. au, Saket, Rushikesh Surwase, and K. H. Kowdiki. "Design of fully automated low cost hydroponic system using labview and AVR microcontroller." 2017 IEEE International Conference on Intelligent Techniques in Control, Optimization and Signal Processing (INCOS). IEEE, 2017. In this paper, a method is proposed to effectively use the data in real time to influence the Counter active steps. The work aims to build a self-controlled automated system which will be in itself smart and intelligent by optimizing the use of present technology. The system uses Microcontroller as DAQ, PH sensor, Water temperature, Actuator is used and is programmed using the C. The cultivation equipped with this system was rather productive than the cultivation without any automated system. The system has a user- friendly interface which is easy to read and easy to control with real time data. The cost of the system was drastically reduced by using the microcontroller based DAQ card.

[2] Palande, Vaibhav, Adam Zaheer, and Kiran George. "Fully automated hydroponic system for indoor plant growth." Procedia Computer Science 129 (2018): 482-488. The system was automated using microcontrollers and sensors to keep human intervention at a minimum. An Internet of Things (IoT) network was created to improve reliability and allow remote monitoring and control if needed. The user is only required to plant a seedling and set initial parameters. Once done, the system is able to maintain the parameters and promote healthy plant growth. The system uses two Arduino boards, Raspberry Pi, PH sensor, Water temperature, Water heater, Aerator is used and are programmed using the Arduino IDE. It is a modified version of the C++ programming language. Fully automated hydroponic system that was low cost and fairly easy for the average user to operate. A few advantages of the Titan Smartponics system is that there is complete control over the aspects that allow a plant to grow, it can be customized to fit the need of a variety of plants, and it does not rely on the outside atmosphere or environment to succeed.

[3] Aishwarya, K. S., M. Harish, S. Prathibhashree, and K. Panimozhi. "Survey on IoT based automated aquaponics gardening approaches." In 2018 Second International Conference on Inventive Communication and Computational Technologies (ICICCT), pp. 1495- 1500. IEEE, 2018.
Remote monitoring and controlling of the artificial environment to eliminate the dependency on the natural habitat to ensure year-round avavailability of all plants and vegetables is one of the main objectives of this project. The project shows that hydroponic systems which are monitored and controlled properly show higher rates of growth and also reduce human dependency. ATMEGA 2560, NODEMCU, Temperature and humidity sensor, PH Raja sensor, soil moisture sensor, Ultra sonic sensor is used and web app is developed. The software is integrated to the hardware of theactual system such that it displays the various parameters like Temperature, Humidity, pH levels etc. on the application that can be downloaded on the smart phones. The traditional farming techniques can easily be replaced by these methods and can be implemented on scales desired by the producer depending on the amounts of produce to be expected.

[4] ArisSiti Nur Adiimahbinti Raja, Khairul IrwanFikri bin Mohammad, Lia SafiyahbintiSyafie, Farah Hanan bintiAzimi, and Suzanna bintiRidzuan Aw. "FrontEnd Development of Nutrient Film Technique for Hydroponic Plant with IoT Monitoring Sys- tem." International Journal of Advanced Trends in Computer Science and Engineering, Volume 9, no. 1.3 (2020).
This paper is focusing on front end development of hydroponic system where users are able to monitor and control two important parameters in plant growth which are EC (electrical conductivity) and pH parameters. This process is executed systematically through the use of internet of thing (IoT) technology. This project make use of ESP32 microcontroller board, LCD display, PH sensor, EC sensor and Blynk app. The user able to control the system either through desktop or smart phones method where the hardware system can be controlled

via finger touch.

This method will give another benefit to user without the need to be at the farmed area.

V. SYSTEM DESIGN

The Project will consist of four modules:

1. Sensor Module
2. Control Module
3. Communication Module
4. User Interface Module

1. Sensor Module: The sensor module for the "Autonomous Sensor Technology in Hydroponics" project includes several key sensors to monitor environmental and water conditions critical for plant growth. The temperature sensor monitors both water and air temperatures. Water level sensor checks the water level and tells that whether it is high or low for plant growth. A humidity sensor keeps track of moisture levels in the air to prevent stress on the plants.

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2. Control Module: The control module for the "Autonomous Sensor Technology in Hydroponics" project is responsible for processingsensor data and managing system responses. It consists of a microcontroller (like Arduino or Raspberry Pi) that receives input from various sensors, including pH, EC, temperature, humidity, and dissolved oxygen. Based on predefined thresholds, the microcontroller triggers actuators such as water pumps, solenoid valves, and grow lights to adjust environmental conditions. Additionally, it ensures real-time monitoring and control through a user interface (mobile app or web dashboard). The system also integrates cloud-based data storage for historical analysis and optimization. This closed-loop system enhances automation, reducing manual intervention.

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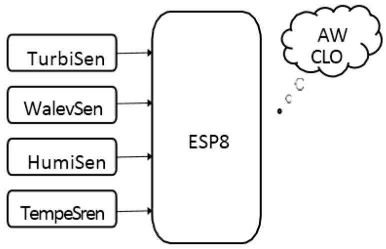
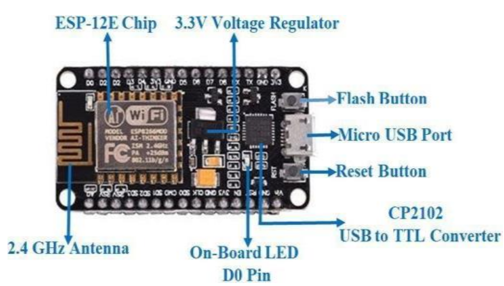


Fi 5. ESP8266Mod



VI. IMPLEMENTATION

Autonomous sensor technology in hydroponics involves integrating various sensors, such as pH, temperature, humidity, light intensity, and nutrient sensors, into the system to continuously monitor plant growth conditions. These sensors collect real-time data, which is then transmitted to a central controller, often based on microcontrollers like the ESP8266, for processing. The system uses this data to automatically adjust environmental factors such as pH levels, nutrient concentration, water flow, and light intensity, ensuring optimal growth conditions. IoT connectivity allows remote monitoring and management through cloud platforms like AWS, enabling farmers to receive real-time insights and alerts. By reducing manual intervention and ensuring precise control, this methodology improves efficiency, reduces resource waste, and enhances plant health.

VII. SYSTEM TESTING AND WEB CODE

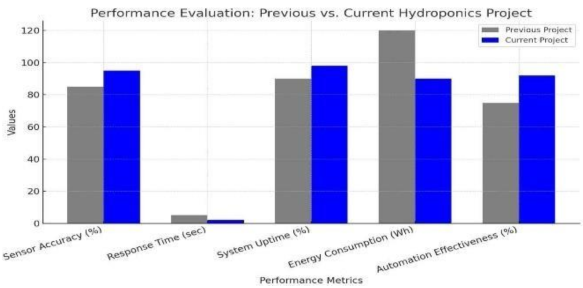
For the Autonomous Sensor Technology in Hydroponics for Monitoring and Controlling Plant Growth project, various types of system testing are essential to ensure that all components work together effectively and deliver reliable performance. The following are key system testing methods:

1. Unit Testing: This focuses on testing individual components such as sensors, actuators, and the software functions that control them. Each sensor (e.g., pH, temperature, humidity) is tested independently to ensure it provides accurate data readings and functions properly in isolation.
2. Integration Testing: After unit testing, integration testing ensures that all system components (sensors, control units, data processing software, and actuators) work together seamlessly. For example, the system should adjust nutrient delivery or lighting automatically based on sensor data inputs.
3. System Testing: This involves testing the entire system in a controlled environment to verify its overall functionality. The system is expected to monitor the hydroponic environment, collect data, process it, and trigger the necessary adjustments (e.g., nutrient levels, temperature) to maintain optimal growth conditions for plants.
4. Performance Testing: This testing measures how well the system performs under various conditions, including high data loads or rapid changes in environmental variables. It ensures the system can handle real-time data and control tasks effectively without delays or failure.
5. Stress Testing: This type of testing challenges the system's ability to function under extreme conditions, such as high moisture, fluctuating temperatures, or electrical surges. It helps identify the system's breaking points and ensures robustness under stressful environmental factors.
6. Field Testing: Once the system passes controlled tests, it is deployed in an actual hydroponic environment for field testing. This allows observation of the system's ability to handle real-world variables, such as inconsistent lighting or plant growth rates, and ensures that autonomous control mechanisms function correctly.

Usability Testing: This involves evaluating the user interface and system settings to ensure ease of use for farm operators or anyone interacting with the system. It includes assessing the accessibility of system controls, data analytics, and how intuitive the

VIII. PERFORMANCE EVALUATION GRAPH

Here is the performance evaluation graph comparing the previous project and current autonomous sensor technology in hydroponics. Blue bars represent the current project, which shows improvements in sensor accuracy, system uptime, and automation effectiveness while reducing response time and energy consumption. Gray bars represent the previous project, which had lower efficiency in most areas.



To ensure prompt response during fire incidents, the Fire Fighting Robot includes a robust alert mechanism. In addition to the remote updates via the cloud dashboard, a local alert system using a piezo buzzer is implemented on the robot. When the flame sensor detects fire or the temperature sensor registers readings above a critical threshold, the buzzer is immediately activated to provide on-site audible warnings. This is particularly useful in environments where internet connectivity may be intermittent or unavailable. Future upgrades to this system aim to incorporate SMS and email notifications through integration with platforms like IFTTT or Blynk, enabling mobile alerts to reach users in real-time and enhancing overall responsiveness. Appendixes, ifneeded, appear before the acknowledgment.

IX. PERFORMANCE EVALUATION

The performance evaluation of the autonomous sensor technology in hydroponics for monitoring and controlling plant growth is critical for assessing the efficiency, reliability, and impact of the system on plant health and resource optimization. The evaluation process focuses on several key performance metrics, which are outlined below:

1. Sensor Accuracy and Reliability

- Temperature and Humidity Sensors: The DHT11 and DS18B20 sensors provide temperature and humidity readings, which are essential for maintaining optimal growth conditions. Evaluating the accuracy and reliability of these sensors is crucial. The system's ability to consistently provide accurate data in different environmental conditions (e.g., variations in ambient temperature and humidity) is tested over time.
- Water Level and Gas Sensors: The water level and gas sensors must be evaluated for their responsiveness and accuracy in detecting fluctuations. This ensures that the system can correctly identify when water levels are low and when gas concentrations reach harmful levels for the plants.

2. System Responsiveness and Adaptability

- Real-Time Control Adjustments: The system's ability to adapt and respond to real- time data is a critical factor. The responsiveness of the control system, which adjusts parameters such as nutrient levels, water flow, and light intensity based on sensor feedback, is evaluated. This includes ensuring that control commands (e.g., adjusting water pumps or lights) are executed without delay.
- Autonomous Decision- Making: The system's autonomous operation in adjusting environmental conditions— without human intervention—is tested by simulating a variety of conditions (e.g., high temperature, low humidity) to ensure that the system can make appropriate adjustments on its own.

3. Energy Efficiency

- Power Consumption: The system’s energy consumption is an important factor for long-term viability, especially in remote locations or systems where energy resources are limited. Evaluating the power usage of the sensors, Wi-Fi communication, and other components ensures the system is optimized for low energy consumption while maintaining high performance.
- Operational Efficiency: The system’s ability to perform required tasks with minimal energy and time is crucial for maximizing crop yield while minimizing resources. This includes evaluating how effectively the system uses electricity, water, and nutrients based on sensor feedback.

4. Data Integrity and Communication

- Sensor Data Accuracy: The integrity of the data collected from all sensors (temperature, humidity, water level, gas concentration) is assessed to ensure that it reflects real-time environmental conditions accurately. Inaccurate data could lead to improper control adjustments, affecting plant growth.
- Wi-Fi and MQTT Communication: The robustness of the communication between the ESP8266 and the MQTT broker is tested. This includes evaluating the frequency and reliability of data transmission over the Wi-Fi network, as well as the MQTT protocol's ability to handle data spikes or transmission failures.

5. Scalability and System Expansion

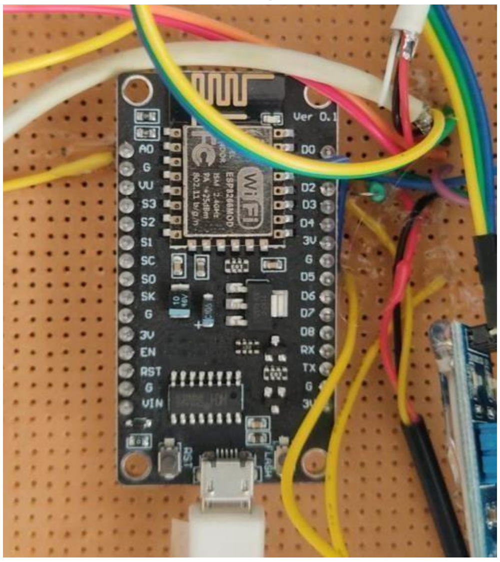
- System Scalability: As the hydroponic system grows, the system’s ability to handle additional sensors and control units is tested. This involves checking the system’s ability to integrate additional sensors (e.g., pH meters, EC sensors) without performance degradation.
- Multi-Site Monitoring: The ability to expand the system to monitor multiple hydroponic setups in different locations is also assessed. This would test the scalability of the MQTT system to handle multiple data streams and provide real- time monitoring across various farms.

6. Long-Term Stability and Durability

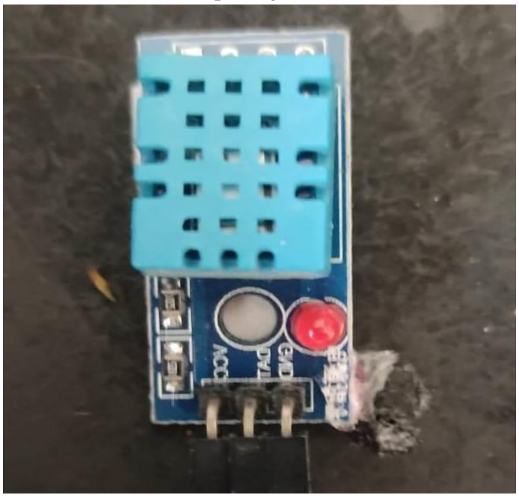
X. RESULTS AND DISCUSSION

This chapter gives the snapshots of results obtained for the autonomous sensor technology in hydroponics for monitoring and controlling plant growth.

1. Wi-Fi Microcontroller: It collects data from all the sensors and send to AWS cloud through wi-fi. It contains a self-calibrated RF allowing it to work under all operating conditions.



2. Humidity Sensor: It measures the moisture and temperature of the air, it provides a digital output. It can be interfaced with any microcontroller like Arduino, Raspberry Pi, etc.



Humidity Sensor

3. CO2 Gas Sensor: A CO2 gas sensor is a device that measures the concentration of carbon dioxide (CO2) in the air. It helps to improve the air quality and enhance the crop growth.

Fig. 9.3 Co2 Gas Sensor

3. Turbidity Sensor: Turbidity sensor measures the TDS (Total dissolved solids). It is a measure of how clear water is or how much light is scattered by particles in the water.

4. Sensor Connection to Wi-Fi Microcontroller: In this below picture we have connected all the sensor to the wi- fi microcontroller. We have grown four plants, growth is monitored by collecting the data from all the sensor and send to the AWS through wi-fi microcontroller.

5. Arduino IDE

Software: Arduino IDE (Integrated Development Environment) is an open- source software. It uses functions from C++ and C for programming.

Arduino IDE is used for writing the codes and uploading them to the Arduino compatible boards.

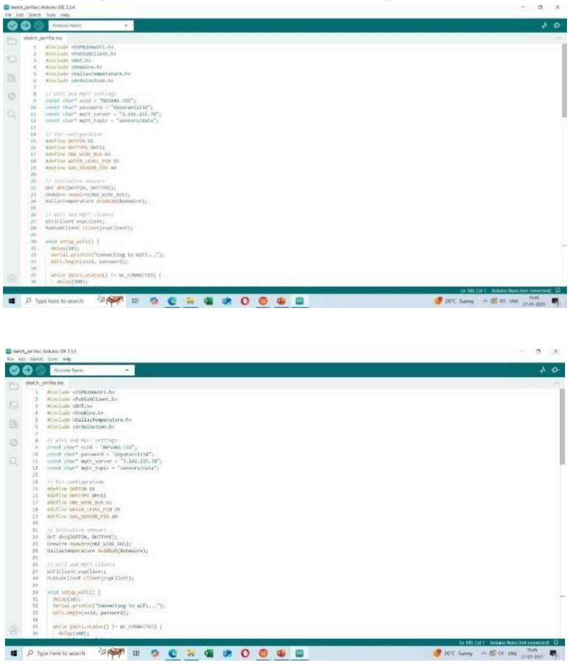


Fig. 9.6 Arduino IDE Software

7. AWS Login Page: We have to create an account in AWS and then we have to sign in by entering account id, username, password.

Fig. 9.7 AWS Login Page

8. AWS EC2 instance: In AWS there are lot of service in that we are using EC2 service. In EC2 we have to launch instance that act as virtual server in the cloud.

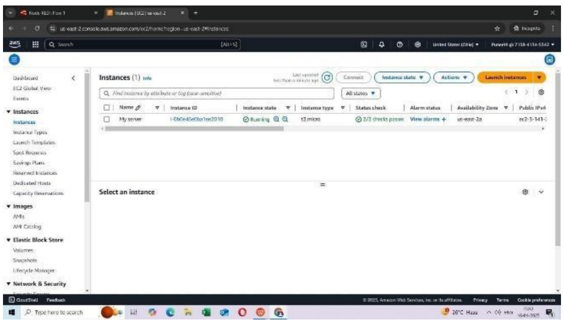


Fig. 9.8 AWS EC2 Instance

9. Node-RED: Node-RED is a software application where we use Node.js as backend. In this application we obtain the messages whether the water is low or high.

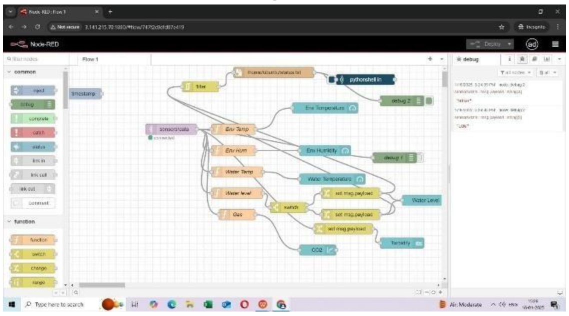
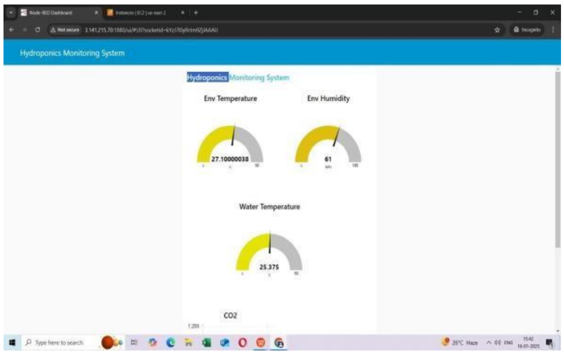


Fig. 9.9 Node-RED



10. User interface for Hydroponics Monitoring System: In this user interface we will monitor environmental temperature, humidity, water temperature, co2, water level and turbidity.

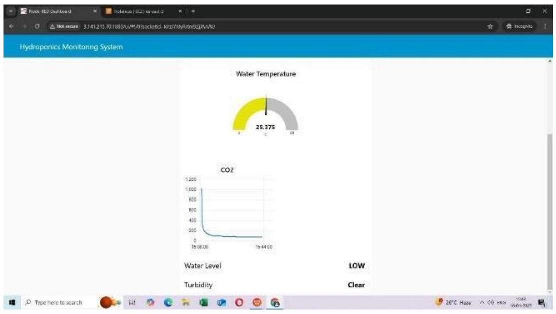


Fig. 9.11 User interface for Hydroponics Monitoring System

11. Hardware Output with Alert Message: We will get alert message in WhatsApp whether water is low or high.

XI. CONCLUSION

The Hydroponics system aimed to create a fully automated hydroponic system that is easy for the average user to operate. Through the use of NODEMCU, Arduino IDE open-source software, and a few sensors this goal was accomplished. Due to the constant feeding of nutrients and water, the hydroponic plants have grown much taller and produced more leaves quicker than the plants growing in normal soil. The user also able to control the system either through desktop or smart phones method where the hardware system can be controlled by using the AWS management console. This method will give another benefit to user without the need to be at the farmed area. The controlled hydroponics system serves as the futuristic smart cultivation technique and save the future of mankind.

In conclusion, autonomous sensor technology in hydroponics significantly enhances plant growth by continuously monitoring and controlling essential environmental parameters such as temperature, humidity, pH, nutrient concentration, and light intensity. By automating these processes, the technology reduces the need for manual intervention, minimizes resource wastage, and ensures optimal growing conditions for plants. Real-time data collection allows for immediate adjustments, improving crop yield, quality, and consistency. Despite challenges such as high initial costs, system complexity, and maintenance requirements, advancements in sensor technology are making hydroponic farming more efficient and accessible. This innovation contributes to sustainable agriculture by reducing water consumption, optimizing nutrient use, and enabling year-round cultivation.

REFERENCES

[1] K. B. Komal and M. K. Bhardwaj, "Implementation of controlled hydroponics in urban infrastructure," IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), vol. 11, no. 5, 2014.

[2] S. Adhau, R. Surwase, and K. Kowdiki, "Design of fully automated low cost hydroponic system using labview and avr microcontroller," in 2017 IEEE International Conference on Intelligent Techniques in Control, Optimization and Signal Processing (INCOS). IEEE, 2017, pp. 1–4.

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[5] R. S. N. A. R. Aris, K. I. bin Mohammad, L. SafiyahbintiSyafie, F. Hanan bintiAzimi, and S. bintiRidzuan Aw, "Front-end development of nutrient film technique for hydroponic plant with iot monitoring system," International Journal, vol. 9, no. 1.3, 2020.

[6] *Research*. [Online]. 10(7), pp. 45–52. Available: https://ijetere.com/papers// AUTONOMOUS-SENSOR TECHNOLOGY- IN- HYDR-OPONICS FOR MONITORING AND - CONTROLLING PL-ANT GROWTH//