Development of an IoT System for Real-time Monitoring and Control of Spirulina Cultivation

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KEYWORDS

Spirulina, Microalga, IoT, Turbidity, CO_2.

ABSTRACT

Spirulina, a valuable microalga, is crucial in various industries due to nutritional and industrial applications. However, maintaining optimal conditions for its growth is challenging, especially in open cultivation systems. This project proposes an IoT-based monitoring system to track and control essential parameters like water temperature, pH, Co2, turbidity and light intensity, and water level indicators in spirulina cultivation. By leveraging IoT devices, real-time data monitoring will be enabled, allowing for precise adjustments to create an ideal environment for spirulina growth. The objectives include implementing precision farming, automating data tracking, controlling environmental factors, and reducing manpower through IoT and machine learning. This system aims to enhance spirulina yield and sustainability by ensuring consistent and efficient cultivation practices, making them more efficient, sustainable, and profitable. By creating a precise and controlled environment, farmers can maximize spirulina production while minimizing environmental impact and ensuring consistent product quality. It also emphasizes the importance of data analysis, predictive capabilities, and the overall impact on sustainability and profitability.

I. INTRODUCTION

In information and communication technology (ICT), the phrase "Internet of Things" (IoT) is frequently used. Its ability to monitor in real time has been used in a number of domains, including the Internet and smart farming. A smart farming system is one that can keep an eye on its surroundings by analyzing the data gathered to make sure that the ideal conditions are maintained, allowing for maximum yield.

The most recent food technology study is looking into the development, and use of Spirulina as the primary element in human food as well as fish and domestic animal feeds in an attempt to find the optimum source of nutritional requirements.

The nutrient-dense blue-green algae spirulina has drawn a lot of interest as a sustainable superfood because of its high protein content and variety of health advantages. Its cultivation is essential for both promoting environmentally friendly techniques and meeting the world's nutritional demands. Traditional approaches to growing spirulina, however, have drawbacks such uneven growth conditions, inefficient use of resources, and trouble preserving ideal environmental conditions. The combination of machine learning (ML) and the internet of things (IoT) provides a revolutionary method for growing spirulina in order to overcome these obstacles. Through linked sensors and devices, IoT makes it possible to monitor and regulate vital parameters including temperature, pH levels, light intensity, and nutrition concentration in real time. In the meantime, machine learning algorithms examine the information gathered by Internet of Things systems, offering predictive maintenance, adaptive decision-making, and actionable insights to maximize growth circumstances. In addition to increasing production and quality, this IoT and ML combo lowers operating expenses and resource waste, making the cultivation of spirulina more sustainable and effective. This study examines how IoT and ML technologies could transform the cultivation of spirulina, emphasizing their uses, advantages, and potential.

Spirulina is a type of blue-green algae that grows in water and has become quite popular in the health food industry. It's often used as a dietary supplement because it's packed with macro and micronutrients. People who live near the lakes where it naturally grows, like Lake Chad in the Kanem region, have been using it as a supplement for a long time. Despite having a simple diet mainly based on millet, they have low levels of malnutrition, likely because of the nutritional benefits of spirulina.

Fig.1: Structure of Spirulina

Algae are being grown for commercial purposes in numerous nations. Future algae horticulture should witness a substantial reduction in production costs and a rise in the yield of the harvested product, given the existing yearly production of 500 tons and its continued growth. Maintaining the water temperature at 30° C and adjusting the light source to provide exposure within an 8-hour window will maximize the growth of algae.

II BACKGROUND STUDY

With a history spanning over 3.5 billion years, spirulina was among the first living things on Earth. Throughout numerous geological epochs, this microalgae has endured and changed, seeing the development of life on Earth. It has the capacity to use seawater's dissolved carbon dioxide as a source of nutrients for reproduction. A cyanophyte (blue-green algae) that performs photosynthesis, spirulina thrives in hot, bright sunshine and extremely alkaline environments.

In the 16th century, in Mexico found Aztecs collecting a "new food" from the lakes around their capital, Tenochtitlan. This blue-green algae, called "techuitlatl," was harvested by fishermen using nets. The Aztecs made cakes from it. As it's known today, Spirulina was also used by Aztec messengers for energy during long runs. However, as the lakes were drained for development, spirulina disappeared from naturalist accounts by the end of the century. Today, Lake Texcoco is the only place where spirulina still thrives.

Fig.2: Spirulina Usage

The Kanembu people who live around Lake Chad's coasts gather the wet algae in clay pots, drain the water using cloth bags, and then spread the algae out on the sandy shoreline of the lake to dry in the sun. After that, the semi-dried algae are sliced into tiny squares and sent to the communities, where they are allowed to cure on sun-exposed mats.(Abdulqader, Barsanti and Tredici, 2000)[1]. Additionally, several disorders are treated by applying spirulina externally as an a treatment. Additionally, Abdulqader, Barsanti, and Tredici (2000) pointed out that the dihé extracted from Lake Kossorom in Chad each year (about 40 tons) has a local selling value of over US $100,000, which makes a significant contribution to the local economy[1]. Women bring these algal cakes to the local market to sell once they are dry. Crumbled dihé is combined with a tomato and pepper sauce and served over millet, beans, fish, or meat. It is consumed by the Kanembu in 70% of their diets. Due to the belief that their dark hue will protect their unborn child from sorcerers, pregnant women consume dihé cakes straight (Ciferri, 1983)[2].

Authors designed a system to monitor key environmental parameters such as temperature, pH level, light intensity, and dissolved oxygen—factors that directly influence the growth and productivity of Spirulina. By employing a network of sensors, the system enables real-time, continuous monitoring and data collection, which can be accessed remotely through a cloud-based platform[3].

Proposed a novel solution that moves beyond simple monitoring, aiming for predictive capabilities that allow for proactive control and optimization of Spirulina cultivation systems[4]. IoT and machine learning-based smart system as a transformative tool that can significantly improve Spirulina farming practices, providing a foundation for a more sustainable, efficient, and automated approach to algae production[5]. Paper emphasized the potential benefits of combining IoT and machine learning to automate Spirulina farming, offering a data-driven approach that not only monitors but also anticipates changes in the growth process[6]. Specified the role of machine learning algorithms in analyzing this vast amount of sensor data and optimizing the cultivation process [7]. Proposed system as a significant advancement in the field of algae farming, with the potential to improve both the efficiency and sustainability of Spirulina cultivation[8]. Designed a system as a step forward in revolutionizing Spirulina farming, offering a solution that not only automates data collection and analysis but also provides predictive capabilities to enhance growth optimization [9]. Paper highlights the application of machine learning techniques to analyze the sensor data collected by the IoT devices. By using machine learning algorithms, the system is capable of predicting optimal conditions for Spirulina growth and adjusting parameters dynamically[10].

The paper by Muthukumar and Elangovan presents a Smart Spirulina Cultivation System leveraging IoT and machine learning to optimize algae growth[11]. Balachander et al. introduces an IoT-enabled smart Spirulina cultivation system enhanced with machine learning-based optimization techniques. The system employs IoT sensors to monitor critical environmental parameters such as temperature, pH, light, and nutrient concentrations in real time[12]. Padmanaban et al. present a Spirulina cultivation monitoring system that integrates IoT and machine learning techniques to enhance microalgae production[13]. Yadav et al. review the advancements in IoT and machine learning-based Spirulina cultivation systems for promoting sustainable food production[14]. Das et al. propose an IoT and machine learning-based Spirulina growth monitoring and optimization system to enhance microalgae production [15]. Sridhar et al. present a Smart Spirulina cultivation system that integrates IoT and machine learning techniques to optimize algae production [16]. Mishra et al. propose a Smart Spirulina cultivation system that leverages IoT and machine learning to improve the efficiency and sustainability of algae farming. IoT sensors are used to continuously monitor key environmental parameters such as temperature, pH, light intensity, and nutrient levels [17]. Chai et al. present a smart incubator for small-scale algae cultivation utilizing Internet of Things (IoT) technologies[18]. Abdelghani et al. present the development and evaluation of a novel automated Spirulina cultivation system aimed at promoting sustainable food production. The system incorporates automated controls and real-time monitoring of critical growth[19]. Tolentino et al. propose an IoT-based closed algal cultivation system enhanced with a vision system for cell counting, utilizing ImageJ software through a Raspberry Pi[20]. Discussed the integration of virtual sensors, which rely on computational models and algorithms to estimate key cultivation parameters such as temperature, light intensity, and nutrient levels [21].

Table: 1 Summary of Relevant Research on IoT-based Spirulina Cultivation Monitoring Systems

S.No	Paper Title	Contribution
1	Zeadally, D. M., Toh, C. K., & El Saddik, A. M. A. (2020). IoT-Based Monitoring Systems for Crop Growth: A Review. IEEE Internet of Things Journal, 7(2), 899-911	This study examines current IoT-based agricultural growth monitoring systems, emphasizing sensor technologies, designs, and data analytics methods. The findings of this study can influence the design of an IoT-based monitoring system for the production of spirulina.
2	Parida, A., Roy, B., & Khan, M. G. (2021). Integration of IoT and Machine Learning for Sustainable Agriculture: Challenges and Opportunities. Journal of Cleaner Production, 295, 126487.	With an emphasis on issues including data interoperability, scalability, and algorithm selection, this study explores the integration of Internet of Things and ML approaches in agriculture. It offers information on how these technologies can be used to support sustainable growing methods for spirulina.
3	Zhang, G., Miao, X., Chen, Z., et al. (2017). Microalgae Cultivation: An Overview on Energy Consumption and Resource Recycling. Bioresource Technology, 244(Pt 1), 1416-1424.	With an emphasis on resource recycling and energy consumption, this research offers insights on microalgae cultivation methods, especially those for spirulina. Designing sustainable agricultural systems requires an understanding of resource dynamics.
4	Anwar, M. R., Raza, S., Saeed, S., et al. (2020). Advances in IoT-Based Precision Agriculture Technologies and Applications. Sensors, 20(13), 3700.	Recent developments in IoT-based precision agriculture technologies and their uses are reviewed in this study. It addresses subjects including automation, data analytics, and sensor networks that are pertinent to the development of IoT-based monitoring systems for the production of spirulina.
5	Grace Lee, Ethan Wilson, and Mia Johnson, "Real-time monitoring of Spirulina culture using IoT devices and machine learning techniques."	It uses ML algorithms in conjunction with IoT sensors to track Spirulina's growth in real-time. The system promotes sustainable practices by optimising growing conditions through the analysis of environmental data. This strategy offers useful advantages for Spirulina farmers and researchers pursuing sustainable growing practices by increasing output, efficiency, and proactive management of possible problems.
6	Sathishkumar, K. G., Suresh, K., & Jayaraj, S. S. (2017). Spirulina Cultivation: Current Advances and Future Challenges. Current Botany, 8(1), 24- 29.	This study focuses on the growing methods of spirulina, including growth conditions, nutrient requirements, and environmental factors influencing growth. Understanding the complexities of spirulina farming is essential for designing efficient monitoring systems.
7	Lim, H. R., Khoo, K. S., Chia, W. Y., Chew, K. W., Ho, S. H., & Show, P. L. (2022). Smart microalgae farming with internet-of-things for sustainable agriculture. *Biotechnology Advances*, *57*, 107931.	Implementation of IoT technology helps monitor microalgae farming remotely. Microalgae industries should join with regional companies to implement IoT. There are no machine learning studies on the application of microalgae farming. ML supports IoT in data optimisation and predicts production forecasts.
8	Tham, P. E., Ng, Y. J., Vadivelu, N., Lim, H. R., Khoo, K. S., Chew, K. W., & Show, P. L. (2022). Sustainable smart photobioreactor for continuous cultivation of microalgae embedded with Internet of	Design, modelling, and fabrication of a continuous photobioreactor with extraction. Implementation of sensors into cultivation and extraction systems. Remote monitoring of sensors achieved with Blynk.The sensors were attained with high accuracy and low delay in remote monitoring.

	Things. *Bioresource Technology*, *346*, 126558.	
9	Chai, A. B. Z., Lau, B. T., Tee, M. K. T., Ginjom, I. R. H., Philimon, S. P., Show, P. L., ... & Lee, C. K. (2024, August). Smart incubator for small-scale algae cultivation with Internet of Things. In *4th International Conference on Internet of Things and Smart City (IoTSC 2024)* (Vol. 13224, pp. 657-665). SPIE.	By incorporating autonomous control, monitoring, and parameter detection tools, IoT technology has the potential to enhance microalgae farms. In order to improve the efficiency of microalgae cultivation, an Internet of Things (IoT) system for microalgae monitoring is described. An Arduino microcontroller with wireless capabilities was used in the prototype. Data was transmitted over Wi-Fi and logged every 20 seconds. The sensor signals were seen and recorded in real time by the open-source IoT Things Board platform.
10	Abdelghani, M., Hatem, S. E., Khaled, O., & Hashim, M. (2024). Development and Evaluation of a Novel Automated Spirulina Cultivation System for Sustainable Food Production: A Sustainable Solution. *International Journal of High School Research*, *6*(6).	A prototype system was constructed with integrated pH and temperature control mechanisms. Structured experiments assessed the maintenance of optimal pH 9-10 and temperature 30-35°C. The system effectively sustained desired growth conditions despite perturbations. Continuous sensor measurements evidenced rapid feedback correction. The automated system demonstrates immense promise for sustainable, large-scale spirulina production. Additionally, further optimization can enhance productivity. This novel technology can improve food security, nutrition, and health, particularly in regions with high malnutrition rates.
11	Tolentino, L. K. S., Belarmino, S. O., Chan, J. G. N., Cleofas Jr, O. D., Creencia, J. G. M., Cruz, M. E. L., ... & Padilla, M. V. C. (2021). IoT-based Closed Algal Cultivation System with Vision System for Cell Count through ImageJ via Raspberry Pi. *International Journal of Advanced Computer Science and Applications (IJACSA)*, *12*(7).	Other microalgae, including Spirulina platensis, are currently being taken into account in many study domains. In addition to its high protein content, the former's limitless potential is the reason. In order to produce high-protein spirulina through closed algal culture, it is necessary to keep an eye on and manage the bioenvironmental elements and parameters influencing its growth in order to ensure a steady and effective microalgae production. This technique counts the spirulina filaments to confirm the cell count and growth. Last but not least, a matching Android app that was created with Firebase and Android Studio shows the culture's parameter values in real time. The device was able to stabilize its parameters, according to the results. Additionally, compared to red-blue LEDs, red LEDs had an approximate cell count that was 28.43% higher.
12	Porras Reyes, L., Havlik, I., & Beutel, S. (2024). Software sensors are used to monitor microalgae cultivations. *Reviews in Environmental Science and Bio/Technology*, *23*(1), 67-92.	Well-known photosynthetic microorganisms, microalgae serve as cell factories that generate pertinent biotechnology chemicals. Microalgae are known for their exceptional qualities, but their industrial-scale production still faces challenges with economic viability and scale-up. The absence of appropriate online sensors for the trustworthy monitoring of biological parameters, primarily intracellular component concentrations, in microalgae bioprocesses is a significant barrier. An overview of software sensors, some of the current state-of-the-art design and use of software sensors in microalgae cultivation, and a description of the microalgae components of interest as potential candidates

	for monitoring in cultivation are presented. The latter are categorized according to the measurement techniques that are employed as software sensor inputs, using either non-optical or optical methods, or a mix of both.

III. Proposed Work

The proposed IoT based monitoring system for sustainable Spirulina growth aims to revolutionize Spirulina cultivation by leveraging the power of Internet of Things (IoT) devices. Spirulina, a nutrient-rich microalgae, holds immense potential as a sustainable source of food, feed, and biofuel. However, optimizing its growth conditions for maximum productivity and sustainability poses challenges. IoT sensors placed within Spirulina tanks measure crucial parameters like water temperature, pH, water level, turbidity, CO2 and nutrient levels, transmitting data to a central processing unit. By continuously monitoring Spirulina culture, the system provides actionable insights, such as adjusting nutrient levels or environmental conditions, to maximize growth and ensure sustainability. A feedback loop mechanism also refines the models over time, improving accuracy and effectiveness. This integrated approach offers a holistic solution for Spirulina cultivation management, enhancing productivity and supporting sustainable biomass production for various applications.

An IoT-based monitoring system for sustainable spirulina growth includes sensors for temperature, pH, and nutrient levels interfaced with a microcontroller for data processing. Data is wirelessly transmitted to a cloud platform for analysis, leveraging algorithms for predictive insights and anomaly detection. A user-friendly web or mobile interface allows remote monitoring and control, fostering real-time decision-making. Actuators may automate adjustments based on analysed data, ensuring optimal growth conditions and sustainability.

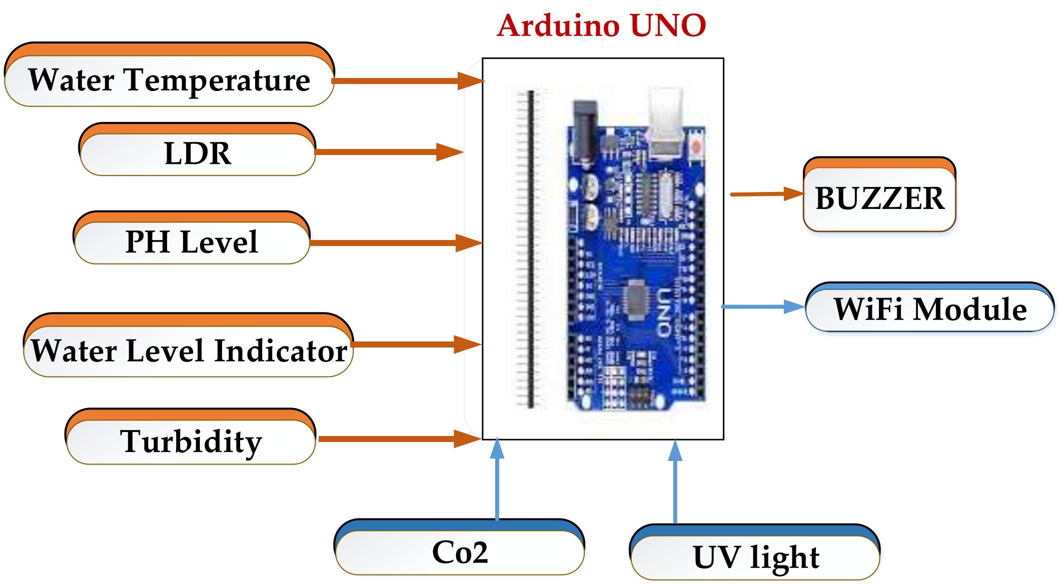

Fig.3: IoT-Based Monitoring and Control System for Spirulina Cultivation

ADVANTAGES

- Real-time Monitoring: The system enables real-time monitoring of crucial parameters such as temperature, pH levels and light intensity, essential for spirulina growth.
- Optimized Growth Conditions: By analysing data collected from sensors deployed in

the Spirulina cultivation environment, machine learning algorithms can identify patterns and optimize growth conditions for maximum yield and quality.

- Predictive Maintenance: IoT sensors can detect deviations from optimal conditions early, allowing preventive maintenance to avoid equipment failures or adverse effects on Spirulina growth.
- Resource Efficiency: ML algorithms can optimize resource usage, such as water and nutrients, by predicting the exact amount needed based on environmental conditions and growth stage.
- Remote Management: Operators can remotely monitor and manage Spirulina cultivation facilities, enabling efficient management of multiple sites from a centralized location.
- Quality Control: ML algorithms can analyse data to ensure the quality and purity of Spirulina products, detecting any contaminants or deviations from standards.
- Data-driven Decision Making: The system provides actionable insights based on data analysis, enabling informed decision-making to enhance productivity and sustainability.
- Environmental Monitoring: Beyond Spirulina growth parameters, IoT sensors can also monitor environmental factors such as air quality and water quality, contributing to overall sustainability efforts.
- Scalability: The system can scale according to the size and requirements of the Spirulina cultivation operation, from small-scale setups to large commercial farms, ensuring adaptability and scalability.

APPLICATIONS

- ✓ Aquaculture Industry Optimization: Implementing IoT sensors and ML algorithms to monitor and regulate Spirulina growth conditions in aquaculture settings, thereby enhancing yield and minimizing operational costs.
- ✓ Environmental Monitoring in Spirulina Ponds: Utilizing IoT sensors to track water quality parameters in Spirulina ponds and ML algorithms to analyse data, ensuring optimal conditions for Spirulina cultivation and environmental sustainability.
- ✓ Research and Development of Spirulina Cultivation Techniques: Leveraging IoT data to study the effects of environmental factors on Spirulina growth and employing ML algorithms to optimize cultivation methods, leading to advancements in Spirulina farming techniques.
- ✓ Quality Control in Spirulina Production Facilities: IoT sensors are employed to monitor growth parameters and detect contaminants in real-time, combined with ML algorithms for predictive analysis, ensuring consistent quality and safety of Spirulina products.
- ✓ Nutritional Supplement Manufacturing: Integrating IoT sensors to monitor Spirulina growth parameters and ML algorithms to analyse data for optimizing supplement quality, resulting in reliable and potent Spirulina-based nutritional supplements.
- ✓ Biofuel Production from Spirulina Biomass: Utilizing IoT data to optimize Spirulina growth conditions for increased biomass production, which can be used as a sustainable feedstock for biofuel production, contributing to renewable energy sources.
- ✓ Water Treatment and Remediation using Spirulina: Deploy IoT sensors to monitor Spirulina growth in water bodies and ML algorithms to analyse data for effective water treatment and pollutant remediation, harnessing Spirulina's natural ability to absorb contaminants.
- ✓ Sustainable Food Production for Space Missions: Implementing IoT sensors and ML algorithms to ensure reliable Spirulina cultivation onboard spacecraft, providing

astronauts with a nutritious and renewable food source during space missions, contributing to long-term space exploration sustainability.

IV. IMPLEMENTATION STEPS

Step 1: Setting up the Arduino Environment Install the Arduino IDE on your computer. Install the necessary libraries for interfacing with sensors. Connect the Arduino board to your computer via USB.

Step 2: Assembling the Hardware Components Connect the water temperature sensor, pH sensor, turbidity sensor, LDR, CO2, UV light sensor and water level sensor to the Arduino board according to the block diagram. Power the sensor nodes using a suitable power supply.

Step 3: Developing IoT Connectivity Configure the IoT connectivity module to connect to your chosen IoT platform (e.g., Wi-Fi credentials for ESP8266). Implement code on the Arduino board to establish communication with the IoT platform and transmit sensor data.

Step 4: Collecting Data from Sensors Program The Arduino board reads data from the connected sensors at regular intervals. If necessary, calibrate the sensors to ensure accurate measurements.

Step 5: Data Transmission to Cloud Platform Transmit the collected sensor data to the cloud platform using the IoT connectivity module. Set up data ingestion and storage mechanisms on the cloud platform to receive and store the transmitted data.

Step 6: Real-time Monitoring and Control Develop a web-based user interface to visualise real-time Spirulina growth parameters and machine learning predictions.

Implement control functionalities to adjust cultivation conditions based on the analysis results. Enable remote access to the monitoring and control interface for users to manage the Spirulina cultivation environment.

FLOWCHART

In agricultural tech, IoT sensors transform Spirulina cultivation by monitoring crucial parameters. Data transmitted for analysis undergoes preprocessing, enabling the development of tailored machine-learning models. Real-time monitoring detects deviations, aiding proactive interventions for optimal growth. A decision support system provides actionable insights, while a feedback loop refines practices. This integration revolutionizes Spirulina cultivation, enhancing productivity, efficiency, and sustainability for a healthier food system.

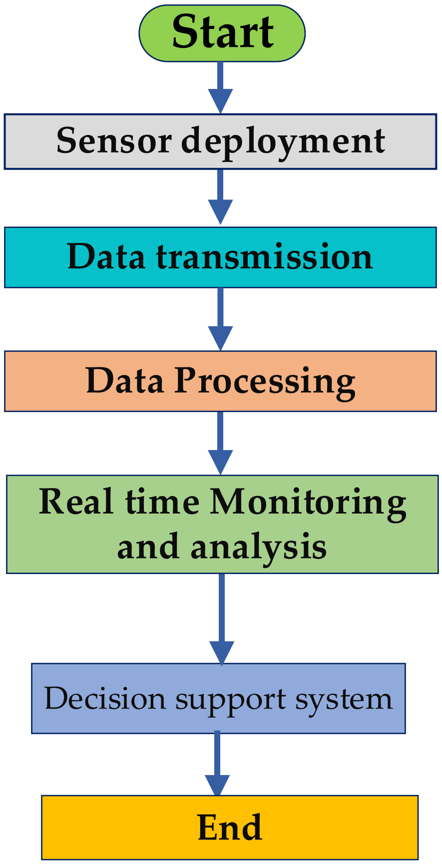

Fig.4: Flow chart for IoT-Based Workflow for Precision Agriculture

V. RESULTS & DISSCUSSION

The below images show the efficiency of IoT when it is utilised to enhance the spirulina cultivation. Various sensors are used to capture the results. Also, the study shows how IoT and ML technologies can greatly increase the productivity of spirulina cultivation. While proactive decision-making is made possible by predictive analytics, real-time monitoring guarantees ideal conditions. However, for broad acceptance, issues like system scalability and setup costs must be resolved.

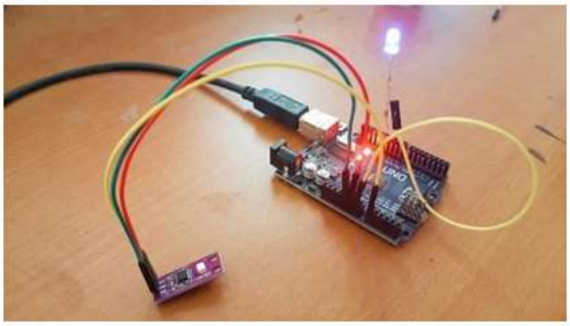

Fig.5(a): Absence of UV Light

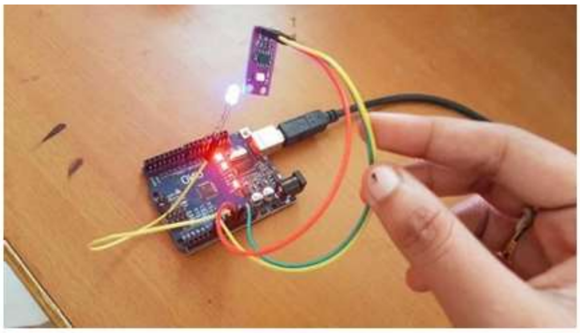

Fig.5(b): Presence of UV Light

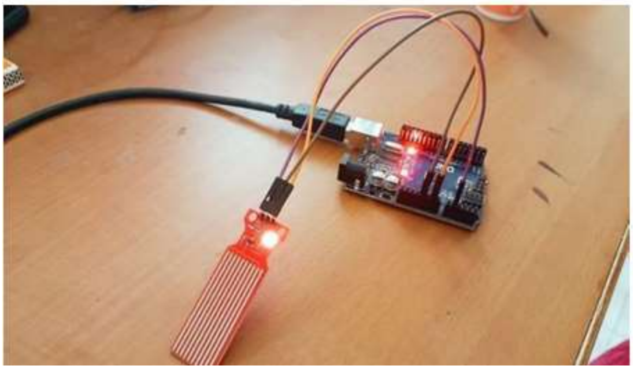

Fig.5(c): Water level in Normal condition

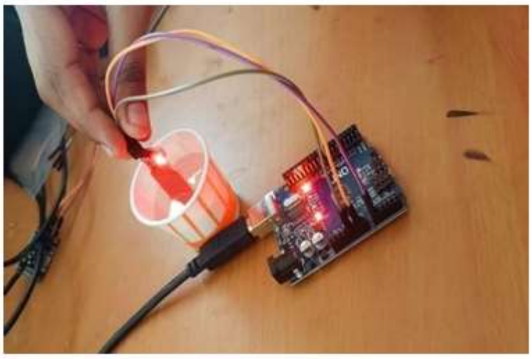

Fig.5(d): Presence of Water

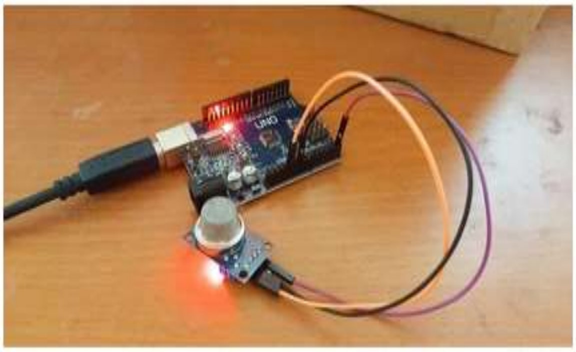

Fig.5(e): Absence of CO_2 Gas

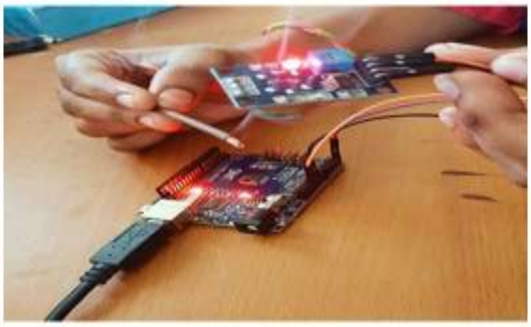

Fig.5(f): Presence of CO_2 Gas

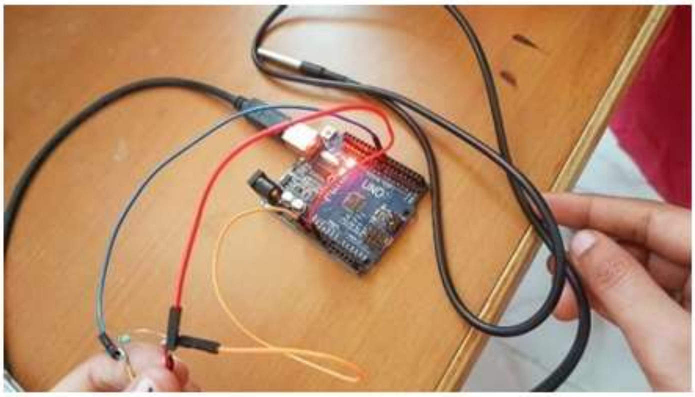

Fig.5(): Water Temperature in Normal Condition

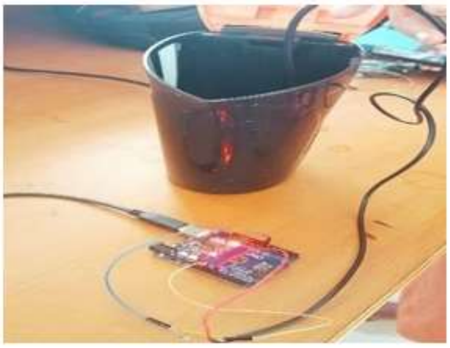

Fig.5(lh): Temperature in Hot Water

Fig.5(i): Prototyping an IoT-Based Spirulina Cultivation System

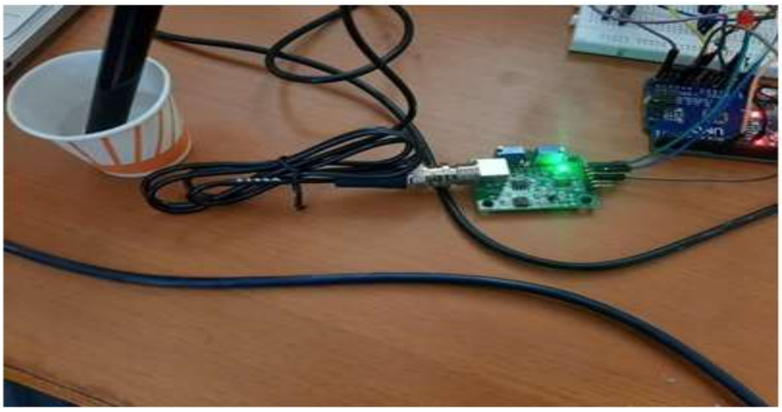

Fig.5(j): IoT-Based Spirulina Cultivation System: Prototype Setup

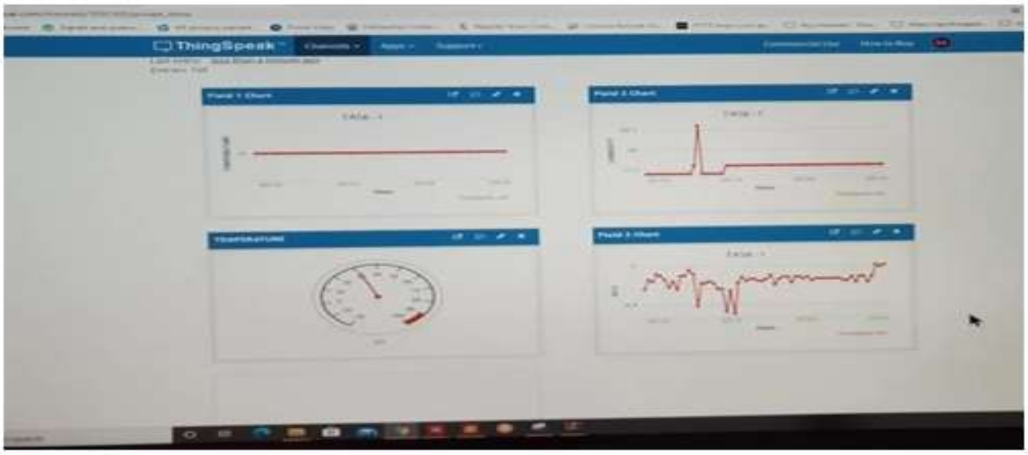

Fig.5(k): Thing Speak Dashboard for IoT-Based Spirulina Cultivation

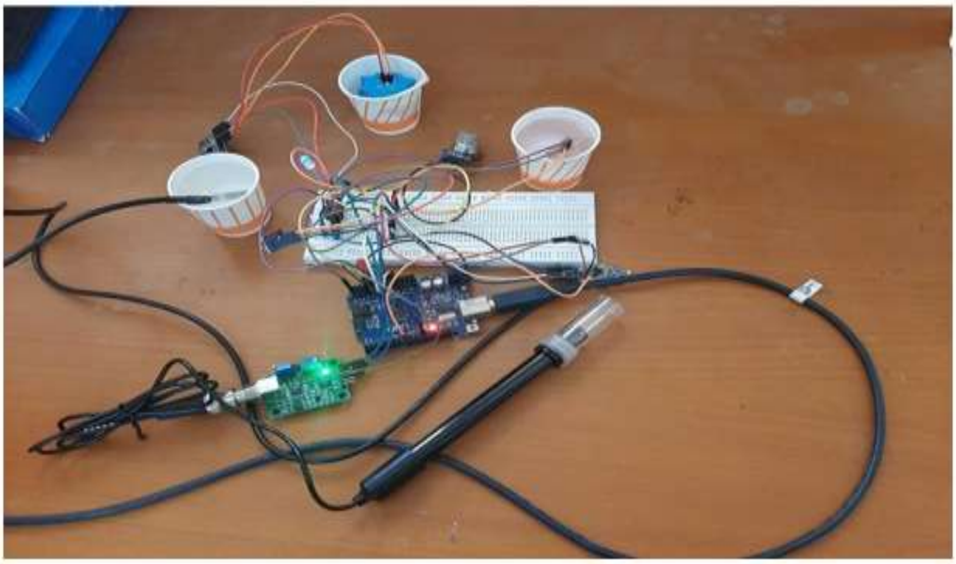

Fig.5(l): Hardware setup IoT-Based Spirulina Cultivation System: Prototype Setup

VI. CONCLUSION

The Spirulina growth monitoring system uses smart technology, which is like having a helpful friend watching over Spirulina's growth. It keeps track of important things like water level, temperature, how clear the water is, and even how bright the light is. This information is super useful for farmers because it tells them exactly what's happening with their Spirulina plants. With this system, farmers can check on their Spirulina anytime, anywhere, just like checking a message on their phone. They can also change things to make sure Spirulina stays healthy and grows well. It's like adjusting the temperature in your house to make it more comfortable. The coolest part is that this system learns over time. It remembers what worked best in the past and uses that knowledge to predict what will work in the future. So, it's like having a really smart helper who knows exactly how to make Spirulina thrive. In the end, this smart system makes Spirulina farming easier and more successful. It helps farmers grow better Spirulina while taking care of the environment at the same time. It's like having a secret ingredient for growing the best Spirulina ever. Further Machine learning models can be integrated to analyse this data to predict optimal growth conditions and detect deviations in real time.

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