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RESEARCH ARTICLE

Revolutionizing Holy-Basil Cultivation With AI-Enabled Hydroponics System

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ABSTRACT This research study focuses on the design and implementation of an IoT-based hydroponic system specifically optimized for the growing of exotic and medicinal plants. The system utilizes the functionality of Azure IoT Hub, Azure Container, and Azure DataBricks, where we employ a logistic regression model on sensor data to classify the upcoming seasonal parameters such as nutrient dispensation, water stream, and light for optimal plant growth. Cloud decision-making is used on the sensor data to identify any potential N, P, and K deficiencies in the plant and calculate the 'HealthinessScore' for the plant. The main boards used in the system are based on the ESP32S chipset with inbuilt Wi-Fi and Bluetooth, which also includes a high-resolution camera module for capturing images of the plants. Additionally, a React-based monitoring portal has been developed to allow for remote monitoring of system parameters and plant health. The chosen plant for this work is the Rama Tulsi (Holy Basil), a medicinal plant known for its medicinal properties. The use of IoT and ML in this hydroponic system aims to improve the efficiency and effectiveness of plant growth while also reducing the need for manual monitoring and intervention. The required nutrients are added to the water according to the crop, and the same water is recycled. Since there is no soil and only water is used, roots will absorb the nutrients faster than those cultivated in the soil. The water will be checked for any contamination or metal ions before being used in the hydroponic farm. The proposed hydroponic system will reduce the time from field to market for the crop, and it requires minimal space compared to conventional agricultural procedures.

INDEX TERMS Hydroponics, Internet of Things, holy-basil plants, machine leaning (ML), healthiness score.

I. INTRODUCTION

India being the country of heritage for the medicinal values of herbs and their usage, Holy basil is one of the most important economic and medicinal crops used in both culinary and medicinal uses. Worldwide, basil-based industries contribute around 15 million USD annually, and more than 100 tons of basil are cultivated for various applications. Basil is one of the most commonly and easily cultivated crops among the other medicinal plants. Even though it can be cultivated easily, basil is prone to many pest and fungal diseases, especially in highly humid regions, resulting in low yields and eventually making plants unfit for medicinal usage. In this context, Hydroponics can provide a promising solution for increasing yield with less space and resource utilization. It also provides a controlled environment that is suitable for any climatic condition. In the hydroponic system, water with nutrients is used as the growing medium instead of soil. The required nutrients are added to the water according to the crop, and the same water is recycled. Since there is no soil and only water is used, roots will absorb the nutrients faster than those cultivated in the soil. The water will be checked for any contamination or metal ions before being used in the hydroponic farm. A hydroponic system will reduce the time from field to market for the crop, and it requires minimal space compared to conventional agricultural procedures.

A smart and modular hydroponic system is one that makes use of advanced technology to automatically monitor and

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adjust the environmental conditions in which plants are grown. The proposed work focuses on the development and implementation of an IoT-based hydroponic system specifically optimized for the growth of exotic and medicinal plants.

The system utilizes the Azure IoT Hub and employs a logistic regression model on sensor data to classify the upcoming seasonal parameters such as nutrient dispensation, water stream, and light for optimal plant growth. Cloud decision-making is used on the sensor data to identify any potential N, P, and K deficiencies in the plant, as well as calculate the healthiness score for the plant. An ESP32S chipset serves as the main board in the system and comes with a 2MP camera module that captures images of plants. The system includes a monitoring portal that enables remote monitoring of plant health and system parameters. The hydroponic system focuses on Rama Tulsi (Holy Basil), a medicinal plant recognized for its medicinal properties. The integration of IoT and ML technologies in the hydroponic system aims to enhance plant growth efficiency and effectiveness while minimizing the need for manual monitoring and intervention.

The major contributions of the paper are as follows:

- Indoor-compatible, hydroponics-based farming method, which prevents water wastage and lets us use any mix of nutrients.
- Automated monitoring to observe any changes in the sensor readings from any remote location.
- Machine Learning (ML) is being used in the future to collect these readings and provide optimal conditions for every plant.

The research work highlights substantial progress made in a number of distinct domains, such as automation, management, indoor plant growth, and remote access to exhaustive information via a web-based dashboard design. This has the potential to promote indoor agriculture, which requires significant upgrades to any cultivation. Hydroponics also leads to an efficient and effective way over usual soil-based cultivation since it prevents water evaporation and also lets us add controlled amounts of nutrients to the mix.

The overall structure of the paper is organized as follows: Section I introduces the prospect of using a computerized dashboard to display plant vitals from an array of IoT sensors. Section II discusses initiatives that employed similar concepts. These demonstrate their benefits and drawbacks. Section III covers tools, parts, software, hardware, methodology, block schematics, materials, and project implementation details. Section IV covers project execution, findings, product outcomes, analysis, and conclusion, and Section V includes conclusion.

II. LITERATURE REVIEW

In recent years, the use of technology in agriculture has increased, with a focus on using Machine Learning (ML) as well as Artificial Intelligence (AI) to increase crop production efficiency. One area where this technology has been particularly useful is in hydroponic farming, where plants are grown in a nutrient-rich solution instead of soil. This type of farming has several advantages, including the ability to grow plants in a controlled environment, the use of less water, and the ability to produce crops year-round. However, there is a lack of research on the use of AI and ML in hydroponic farming, particularly in the cultivation of exotic and medicinal plants.

One of the primary areas of research in hydroponic farming is the use of the Internet of Things (IoT) to monitor and control the environment within the greenhouse. Farooq et al. conducted a survey on the IoT-enabled greenhouse agriculture enabling technologies, applications, and protocols. Sensor-based monitoring systems were discovered to be the most widely used technology, with a focus on monitoring temperature, humidity, and nutrient levels [1]. Bhargava et al. also used sensor fusion to create an intelligent hydroponic farming and nursing system that increased crop production efficiency. It also allowed farmers to monitor the health of their plants in real time and make adjustments to their nutrient supply as needed [2].

Another area of research is the use of single-board computing for hydroponic plant monitoring. Mogi and Dharma developed a system that uses a single-board computer to monitor and control the environment within a hydroponic greenhouse. This system was able to increase food security in Bali by providing real-time monitoring of the plants' growth and nutrient levels [3]. Zhang et al. also used a single-board computer to create an environment monitoring system in a greenhouse for a hybrid of hydroponics and aquaculture. This system was capable of accurately measuring the temperature, humidity, and nutrient levels of water and soil, as well as alerting farmers to environmental abnormalities [4].

The use of AI and ML in hydroponic farming is still in its infancy, but there are a few studies that have been conducted. Mehra et al. predicted plant growth using an IoT-based hydroponic system and deep neural networks. This system accurately predicted plant growth 96% of the time [5]. Naphtali et al. used IoT to create an intelligent hydroponic farm monitoring system that could detect and diagnose plant diseases in real time. This system was also capable of detecting nutrient deficiencies in plants and recommending nutrient levels for optimal growth [6].

One of the main challenges in hydroponic farming is the efficient use of water and nutrients. Grewal et al. conducted a study on the water and nutrient use efficiency of a low-cost hydroponic greenhouse for a cucumber crop. They found that the hydroponic system was more efficient in the use of water and nutrients compared to traditional farming methods [7]. Rius-Ruiz et al. created a computer-operated analytical platform for nutrient determination in hydroponic systems, which improved nutrient management efficiency. This system accurately measured the nutrient levels in the water and soil and alerted farmers to any nutrient deficiencies [8].

The design of an IoT-based hydroponic system for indoor plant growth has also been reported with the use of an Arduino microcontroller and various sensors to monitor and control the growing conditions, including temperature, humidity, pH, and nutrient levels [9], [10]. Ezzahoui et al.

used IoT to compare hydroponic and aquaponic farming technologies. They discovered that hydroponic systems are easier to manage and have a lower disease risk, whereas aquaponic systems are more sustainable and can produce both fish and plants [11]. Claussen investigated the effect of nitrogen source and nutrient concentration on the growth, water use efficiency, and proline content of hydroponically grown tomato plants. The study found that ammonium nitrate resulted in better growth and water use efficiency than other nitrogen sources but also increased proline content, indicating a potential for salt stress [12]. In Sweden, Gentry investigated the integration of vertical hydroponic farming and district heating. The study discovered that waste heat from district heating systems could be used to boost hydroponic system efficiency and reduce overall energy consumption [13].

Lin et al. investigated the effects of red, blue, and white LED lights on the growth, development, and edible quality of hydroponically grown lettuce. They found that red and blue light increased growth and development, while white light resulted in better quality lettuce [14]. Qazi et al. conducted a critical review of IoT-enabled and AI-enabled smart agriculture, highlighting current challenges and future trends. The study noticed that IoT and AI technologies can significantly improve the efficiency and sustainability of hydroponic farming systems [15].

Abu-Shahba et al. compared the cultivation and biochemical analysis of iceberg lettuce grown in sand soil and hydroponics with or without microbubbles and macrobubbles. They found that hydroponics with microbubbles resulted in the highest yield and nutritional content [16]. Richa et al. examined the use of ion-selective electrodes and IoT for advanced hydroponic solution monitoring. According to the findings of the study, these technologies can provide accurate and real-time data for optimizing nutrient management and increasing crop yield [17]. Bassiouny et al. investigated the use of a hydroponic nutrient solution as a potential draw solution for fertilizer-drawn forward osmosis and hydroponic agriculture of lettuce. The study found that the hydroponic nutrient solution could be an effective and sustainable draw solution, but further research is needed for optimizing the process and scaling it to commercially needed levels [18].

Saraswathi et al. proposed using IoT to automate monitoring and control of environmental parameters such as temperature, humidity, and nutrient levels in hydroponic greenhouse farming. Their system used various sensors and actuators to achieve optimal crop growth conditions, and the results showed increased yield and produce quality [19]. G. Marques et al. developed an enhanced environmental monitoring system for hydroponic agriculture using IoT technology. Their system integrated various sensors and a wireless network to enable real-time monitoring of critical parameters such as pH, temperature, and humidity and provided alerts to farmers when anomalies were detected. The system demonstrated improved crop quality and reduced resource consumption [20].

Dhal et al. presented a data-driven, real-time monitoring system based on IoT for controlling heavy metals in hydroponic setups to ensure optimal lettuce growth. The system used various sensors to measure heavy metal concentrations in water and soil, and it gave farmers advice on the best nutrient and water management practices to reduce heavy metal accumulation in crops [21]. In another study, Yang and Kim compared the nitrogen and phosphorus mass balance in tomato, basil, and lettuce-based aquaponic and hydroponic systems. Their results showed that aquaponic systems had a higher nitrogen utilization efficiency and a lower phosphorus discharge than hydroponic systems. The study highlights the potential of aquaponic systems for sustainable agriculture [22].

Triastinurmiatiningsih et al. studied the effects of nitrogen, phosphorus, potassium, and calcium deficiency on okra growth in hydroponics. Their findings revealed that nutrient deficiencies in any of the nutrients significantly reduced plant growth and yield, and the severity of the effect varied depending on the type of nutrient deficiency [23]. In another study, Chen et al. studied the effects of nitrogen, phosphorus, potassium, calcium, and magnesium deficiency on the growth and photosynthesis of Eustoma. Their results showed that nitrogen deficiency had the most significant impact on plant growth and photosynthesis, followed by phosphorus and potassium deficiencies. Calcium and magnesium deficiency had little effect on growth and photosynthesis. This study emphasizes the importance of maintaining optimal nutrient levels for plant growth in hydroponic systems [24].

Despite the benefits of hydroponic farming, AI and ML in exotic and therapeutic plant production are understudied. This discovery could boost crop yields and supply medicinal herbs. The hydroponic growing of exotic and therapeutic plants requires more study in AI and ML. New algorithms and models that forecast plant development and optimize water and fertilizer use could cover this research gap. These algorithms and models could be utilized to create intelligent hydroponic systems that continuously track and alter greenhouse environments, enhancing effectiveness and productivity. AI and ML may additionally detect and diagnose plant illnesses in real time, helping farmers safeguard crops from damage. Overall, the use of AI and ML in hydroponic farming has the potential to revolutionize the industry. By using these technologies, farmers will be able to increase their productivity and efficiency while reducing water and nutrient use. Furthermore, the use of AI and ML can provide a sustainable source of exotic and medicinal plants, which has the potential to improve food security and promote health and wellness. The schematic view of the proposed AI-enabled hydroponics" system is shown in Figure 1.

III. METHODOLOGY

A. TOOLS, FRAMEWORKS AND PARTS USED

1) HARDWARE PARTS ACQUIRED

The proposed work aims to develop a hydroponics system that utilizes various sensors and actuators to monitor and

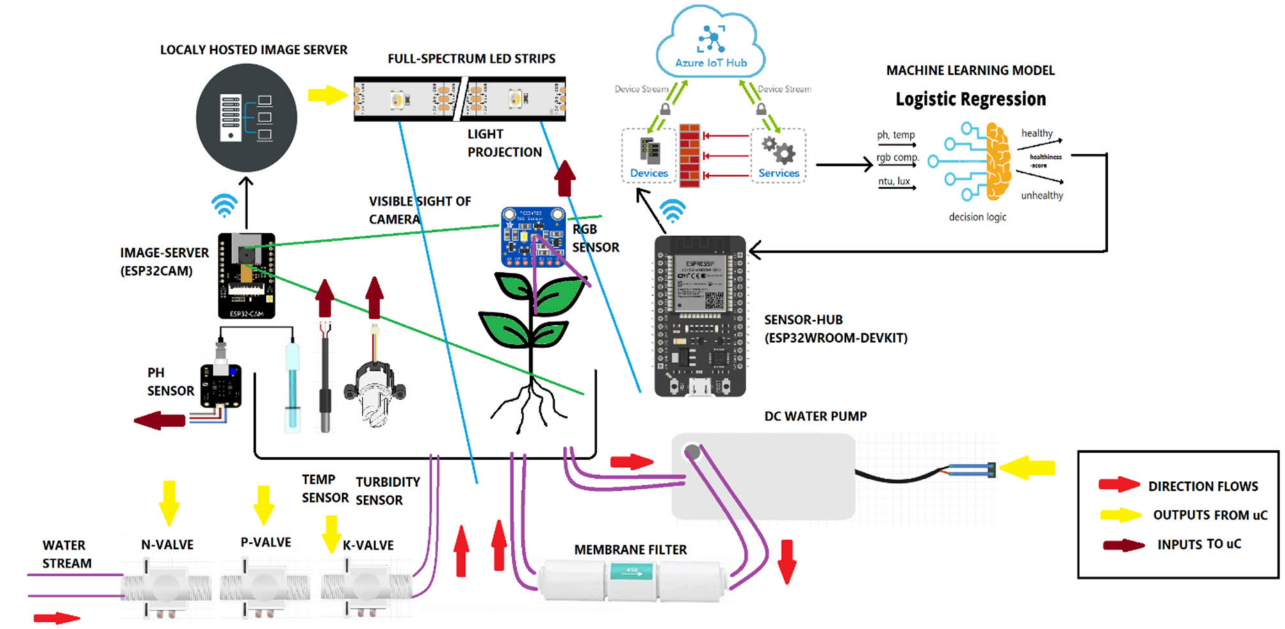


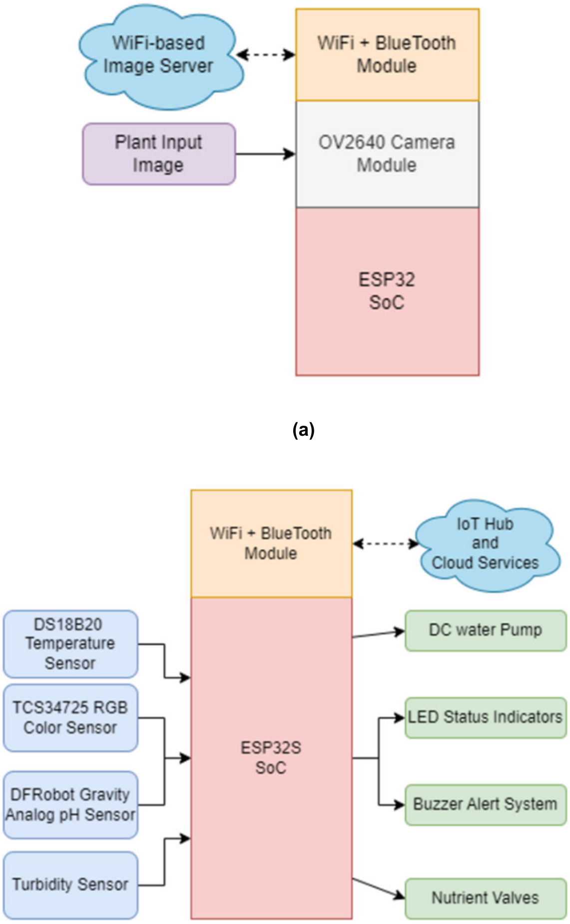
FIGURE 1. Hardware schematic view of the proposed "AI – Enabled Hydroponics" system.

control the growth of plants in a water-based environment. The system will use a combination of wireless connectivity, data processing, and automation to ensure optimal plant growth and efficiency [25].

- ESP32-CAM: The ESP32-CAM is a small microcontroller-based board that also has a camera module integrated to take images and stream videos over Wi-Fi. It is based on the ESP32 microcontroller and features an OV2640 camera sensor with a resolution of up to 2 megapixels. It also includes a built-in flash for low light conditions. It is used in the proposed hydroponic system for monitoring purposes.
- ESP32-WROOM DEVKIT: The ESP32-WROOM is a powerful Wi-Fi and Bluetooth enabled microcontroller board. It is the main sensor-hub to which all the sensors are connected in the proposed system. It is based on the ESP32 microcontroller and features a dual-core processor, up to 240MHz of clock frequency, 520KB of SRAM, 4MB of flash memory, and a range of peripheral interfaces. The hardware block diagrams of the ESP32-CAM and ESP32-WROOM are shown in Figure 2 (a) and (b), respectively.
- TCS34725 RGB color sensor: The TCS34725 is a high-precision color sensor that can detect a wide range of colors. It is used in the proposed system to check the color of the water to guess the nutrient content. It can detect the color temperature, which can be used to determine the nutrient level of the water.
- DS18B20 temperature sensor: The DS18B20 is a digital temperature sensor with a temperature range of -55°C to +125°C. It is used in the proposed system to check the temperature of the water. It is a low-cost sensor with high accuracy and can be easily interfaced with the ESP32-WROOM module.
- Water-Turbidity Sensor: The water turbidity sensor is used to determine how cloudy or hazy the water is. In NTU units, it can detect the amount of suspended particles in the water. This sensor is important in hydroponics as it can indicate the presence of algae, sediment, or other impurities that may harm the plants. The data from the sensor can be used to adjust the nutrient levels and control the water flow.
- DFRobot Gravity Analog pH Sensor: The DFRobot Gravity Analog pH Sensor is a high-precision sensor capable of measuring the pH of water. It is used to determine the acidity or alkalinity of the water in the proposed system. The sensor outputs a voltage that can be easily converted to a pH value via a simple calibration procedure.
- Buzzer and LEDs for status alerts: The buzzer and LEDs (Red, Yellow, and Blue) are used to provide status alerts in the proposed system. They can indicate the presence of any issues or provide feedback on the current status of the system. For example, the buzzer can alert the user if the water level is too low or if the nutrient levels are not ideal.
- Plastic 15" tray: The plastic tray is used to hold all the parts of the proposed system together. It is lightweight and easy to clean, making it ideal for hydroponic applications. The tray can be used to hold water, sensors, and plants.
- Submersible water pump: The water pump is used to circulate the water in the hydroponic system. It can be controlled using the ESP32-WROOM connected to the relay module to adjust the flow of water. The pump can

help distribute the nutrients evenly and provide oxygen to the plants. It is also useful for maintaining the water's temperature and preventing stagnation.

- Full-spectrum LED lights: These lights are a popular choice for indoor plant growth as they emit a balanced range of wavelengths similar to natural sunlight. These lights can provide plants with the necessary light energy for photosynthesis even in low natural sunlight-intense environments. Additionally, they consume less energy and generate less heat compared to traditional lighting systems.
- 5V Dual Channel Relay Module with Optocoupler: In this project, the 5V Dual Channel Relay Module with Optocoupler for ESP32 is a versatile device capable of controlling both a submersible water pump and LED lights at the same time. Its optocoupler ensures high isolation and safety, making it an easy and efficient way to manage multiple devices.



(a)

(b)

FIGURE 2. Hardware block diagram of (a) ESP32-CAM (b) ESP32-WROOM DEVKIT.

2) SOFTWARES AND FRAMEWORKS CHOSEN

The software tools utilized include Arduino IDE, Azure's services, namely IoT-Hub, Storage Containers and DataBricks, and Python and its libraries. Each of these software tools serves a specific purpose and helps in achieving the desired outcome of the proposed system [25].

- Arduino IDE: Arduino is an open-source platform widely used for developing IoT projects. We chose Arduino IDE as our microcontroller software because it allows us to easily program and control the microcontroller that is in charge of monitoring and controlling the hydroponic system. The IDE also includes a wide range of libraries and tutorials, making it simple for beginners to get started with IoT projects.
- Azure IoT-Hub: The Azure IoT-Hub is a cloud-based platform for connecting, monitoring, and managing Internet of Things devices. We chose Azure IoT-hub because it allows us to remotely access and control the hydroponic system from anywhere. Additionally, Azure IoT-hub provides advanced features such as security, scalability, and device management, making it an excellent choice for our IoT-based project.
- Containers and blobs: We are using a container that contains many blobs that stores any data that is being continuously sent to the IoT-Hub in the form of JSON files (blobs) and sorts automatically according to time.
- Azure DataBricks: We are using Azure DataBricks to make the data in our containers readable and accessible to us and the user. It is also being used to run logistic regression to classify whether the plant's current state is healthy or not in terms of 'HealthinessScore'.
- Python and its libraries: Python is a widely used programming language that is particularly suitable for IoT projects. We chose Python and its libraries because they offer a wide range of libraries and tutorials that are useful for IoT projects. Additionally, Python libraries such as NumPy, Pandas, and Matplotlib are essential for data analysis, which is necessary for monitoring and controlling the hydroponic system.

3) HYDROPONIC NUTRIENTS

Hydroponic nutrients are essential in hydroponic farming, as they provide plants with all the necessary nutrients for optimal growth and development. Unlike regular fertilizers, hydroponic nutrients are specifically formulated to deliver a balanced mix of essential minerals, trace elements, and other nutrients that plants need for healthy growth. These nutrients are readily available to plants as they are dissolved in water, allowing for efficient uptake and utilization. Additionally, hydroponic nutrients can be adjusted to meet the specific needs of different plants at different stages of growth, leading to higher yields and better-quality crops. Nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), boron (B), molybdenum (Mb), and chlorine (Cl) are essential nutrients for hydroponics.

TABLE 1. **Plants and their growth characteristics.**

Plant Name	Sun-light (Lux)	Sunlight (Hours per Day)	Water Turbidity (NTU%)	pH	Water Temperature (°C)	Nutrient Composition ratio (N:P:K)
Aloe vera	2000-3000	6-8	0-10	6.0-7.0	18-24	1:1:1
Echinacea	4000-6000	12-16	0-10	6.0-7.0	20-22	2:1:2
Milk thistle	5000-7000	12-14	0-10	6.0-7.0	20-24	1:2:2
Chamomile	6000-8000	12-14	0-10	6.0-7.0	18-23	2:1:2
Peppermint	8000-10000	12-16	0-10	6.0-7.0	18-24	2:1:2
Turmeric	8000-10000	12-16	0-10	6.0-7.5	25-30	2:1:2
Sage	6000-8000	12-14	0-10	6.0-7.0	20-24	2:1:2
Lemon balm	6000-8000	12-14	0-10	5.5-7.0	20-24	2:1:2
St. John's wort	8000-10000	12-16	0-10	5.5-7.5	18-24	1:1:1
Tulsi (Holy-Basil)	**8000-10000**	**12-16**	**0-10**	**5.5-6.5**	**18-25**	**3:1:2**

Nitrogen (N), phosphorus (P), and potassium (K) are the three most important nutrients for hydroponic plant growth. Nitrogen is a crucial component of chlorophyll, which is responsible for the plant's ability to carry out photosynthesis and produce energy. Phosphorus is needed for root growth, flower and fruit development, and seed production. Potassium is essential for overall plant health, as it helps regulate water balance and assists in the transportation of nutrients throughout the plant.

FIGURE 3. **Nutrient solutions utilized for the proposed hydroponic farming of Holy-Basil plant.**

In hydroponics, these three nutrients are typically supplied in the form of a balanced fertilizer solution tailored to the specific needs of the plants being grown, as shown in Figure 3. Proper levels of N, P, and K are crucial for healthy plant growth, and deficiencies in any one of these nutrients can lead to stunted growth, poor yields, and decreased plant vigor.

Monitoring and maintaining a proper balance of N, P, and K is therefore critical in hydroponics to ensure healthy plant growth and maximum yields.

4) IDEAL GROWTH PARAMETERS FOR HYDROPONIC PLANTS

To gather information about the optimal growing parameters of various medicinal plants in DWC hydroponics, we undertook a thorough research and observation process. Firstly, we compiled a list of common medicinal plants and conducted extensive research to identify their preferred growing conditions. This helped us establish a baseline understanding of the ideal conditions required for each plant's growth. After that, we visited several nurseries specializing in hydroponic gardening to observe how these plants are grown in DWC systems. During our visits, we carefully examined the physical condition of the plants and noted any signs of stress or disease. We also observed how the plants were being nourished and managed by the experienced growers.

During our interactions with the growers, we asked them about the optimal sunlight exposure, water turbidity, pH levels, water temperature, and nutrient composition for each plant. We probed them to provide detailed insights into how they manage these parameters in their DWC hydroponic systems to ensure optimal growth of the plants.

Based on our observations and discussions with the experienced growers, we collected and compiled data on the optimal growing parameters for each plant in Table 1.

The table includes information on the ideal pH range, temperature, nutrient composition, light exposure, and water turbidity levels for each plant. This information has provided us with a comprehensive understanding of the requirements for growing these medicinal plants in DWC hydroponic systems. Table 1 describes the optimal growing parameters of these plants in DWC hydroponics that were formulated. Rama Tulsi (the plant of our interest), also known as Holy Basil (or Ocimum Tenuiflorum), is a commonly grown medicinal herb that is revered in Indian culture for its numerous health benefits. We learned that when growing this plant hydroponically, it is important to pay attention to several key parameters to ensure optimal growth and yield from the system.

Firstly, Rama Tulsi requires a minimum of 8 hours of full sunlight per day, with an ideal range of 12-16 hours. The ideal sunlight intensity for Rama Tulsi is around 8000-10000 lux, which can be achieved using Full-Spectrum LED growth lights. In terms of water turbidity, Rama Tulsi prefers clear water with a turbidity range of 0-10 NTU.

The pH of the water solution should be maintained between 6.0 and 7.0 for optimal growth and nutrient uptake, while the ideal water temperature should be maintained between 18 and 24°C. Rama Tulsi has a moderate nutrient requirement and grows well with a nutrient composition of 3:1:2 NPK (nitrogen, phosphorus, and potassium).

Furthermore, Rama Tulsi is susceptible to a variety of pests and diseases, including aphids, spider mites, and powdery mildew. It is critical to keep the growing environment clean and to inspect the plants on a regular basis for signs of infestation.

5) NPK DEFICIENCIES

Nitrogen, phosphorous, and potassium deficiencies are very common problems in hydroponic systems and can negatively affect plant growth and yield. Nitrogen (N), phosphorus (P), and potassium (K) are the three primary macronutrients that plants need in relatively large quantities to grow and develop properly. Nitrogen is essential for plant growth as it is a major component of amino acids and chlorophyll, which are critical for photosynthesis. Phosphorus plays a crucial role in energy transfer within the plant, and it is necessary for the growth and development of roots, flowers, and fruits. Potassium is involved in the regulation of plant water balance and is required for the synthesis of proteins and carbohydrates. When one or more of these macronutrients is deficient, plants can exhibit a range of symptoms, including stunted growth, yellowing of leaves, and reduced fruit or flower production.

Identifying and correcting nutrient deficiencies is essential to maintaining healthy and productive plants in hydroponic systems, and this can be accomplished through regular monitoring and adjustment of nutrient levels based on plant needs. The ideal nutrient concentrations for Rama-Tulsi cultivated in hydroponics are listed in Table 2.

We also derived Table 3 by observation of several NPK deficient plants, observing it in 16-bit (0-65535) values for each of the NPK deficiencies.

TABLE 2. Ideal nutrient concentrations in hydroponics for rama tulsi.

Plant Nutrient	Concentration Range (ppm)			
	Optimal	Acceptable	Deficient	Toxic
Nitrogen (N)	150-300	100-350	< 100	> 500
Phosphorus (P)	30-60	20-80	< 20	> 100
Potassium (K)	200-400	150-450	< 150	> 600
Calcium (Ca)	100-200	50-300	< 50	> 500
Magnesium (Mg)	50-100	30-150	< 30	> 300
Sulfur (S)	100-200	50-300	< 50	> 500
Iron (Fe)	2-5	1-10	< 1	> 20
Manganese (Mn)	0.5-2	0.2-5	< 0.2	> 10
Zinc (Zn)	0.5-1	0.2-2	< 0.2	> 5
Copper (Cu)	0.1-0.5	0.05-1	< 0.05	> 2
Boron (B)	0.5-2	0.2-5	< 0.2	> 10
Molybdenum (Mo)	0.05-0.2	0.02-0.5	< 0.02	> 1

TABLE 3. 16-bit rgb composition ranges for npk deficiencies in rama tulsi.

Nutrient Deficiency	Red (R)	Green (G)	Blue (B)
Nitrogen (N)	65536	65536	0
Phosphorus (P)	32768	0	32768
Potassium (K)	65536	32768	0

To gather RGB values for good and bad Rama Tulsi plants' leaves, we physically visited several nurseries and used a TCS34725 RGB color sensor to capture color data. The first step would be to identify a set of healthy and unhealthy Rama Tulsi plants by visually inspecting the leaves for signs of discoloration or other symptoms of nutrient deficiencies or plant diseases. The next step would be to use the TCS34725 sensor to measure the RGB values of the leaves. The TCS34725 is a color sensor that can measure red, green, blue, and clear light components and convert them to digital signals. The sensor can be placed directly on the surface of the leaf to measure its color. Once the RGB data was collected, we analyzed it to identify any patterns or trends related to the health of the plants. This data helped us to better understand the relationship between nutrient deficiencies and plant health and to develop more accurate and reliable methods for assessing plant health in the hydroponic system.

B. HARDWARE METHODOLOGY

The selection of hardware in this system provides a comprehensive solution for monitoring and controlling a hydroponic environment for optimal growth and yield, precisely with the help of IoT and ML. The implementation of the hardware relies on the following steps:

- Setting up the Hardware: Assembling the ESP32-CAM microcontroller and attaching the input sensors (DS18B20, TCS34725, Turbidity Sensor, and DFRobot Gravity Analogue PH sensor) and output hardware (DC water pump, LED and buzzer status indicators, valves for nutrient flow) to the system.
- Programming the Microcontroller: To collect data from the input sensors and control the output hardware, the microcontroller has to be programmed. This includes coding the device to read the data from the temperature and humidity sensor, color sensor, and pH sensor and then passing it to the cloud services.
- Connecting to Cloud Services: Both of the ESP32-CAM and ESP32-WROOM DEVKIT microcontrollers have inbuilt Wi-Fi, which can be used to connect the device to Wi-Fi and then to Azure IoT-Hub, use it as an image server, and other related cloud services. This allows for real-time monitoring and control of the system from a remote location.
- Machine Learning Integration: Machine learning (ML) algorithms are capable of analyzing sensor data in the system. This will help the system decide when to water the plants, alter the nutrients flow, validate, and set the optimum conditions for higher output.
- Testing and Deployment: To ensure proper operation, the system must be checked after setup and programming. This includes validating sensor data, output hardware, and cloud service connectivity.
- Maintenance and Upgrades: The system will need regular maintenance and upgrades to ensure it continues to function correctly. This includes replacing batteries, sensors, and other components as needed and updating the software to fix bugs and add new features.

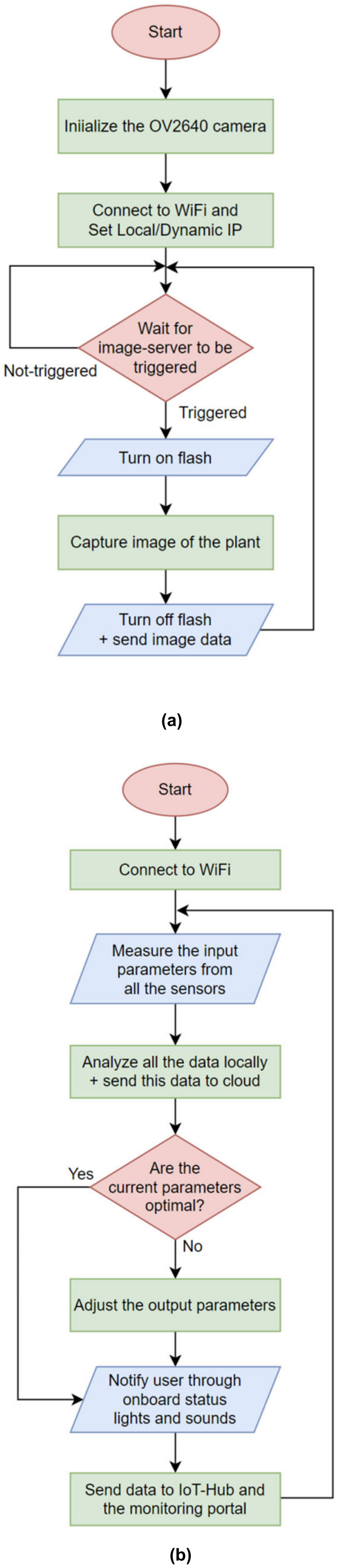
C. SOFTWARE METHODOLOGY

After initialization of the system, gathering data from the sensor-hub's interconnected sensors (such as temperature, turbidity, pH, and RGB intensity) is the initial stage. Figure 4 shows the local analysis and cloud processing flow. Following that, validation of the plant growth parameters is essential. In the event that the presets are not optimal, the system will change them as necessary. After setting parameters, the device will alert the user via status indicators and a buzzer. Azure IoT-Hub and a remote monitoring portal will retrieve the data. The procedure repeats again, monitoring and modifying conditions for optimal plant growth.

When the sensor-hub refreshes its local IP, the image-server subsystem generates a 1600×1200 pixel image. Azure DataBricks services will consistently classify and report the "HealthinessScore" each minute of the day.

1) COMPUTATION OF HEALTHINESS SCORE

The Python code takes input parameters such as temperature (TEMP), turbidity in percentage (NTU%), pH (pH), color

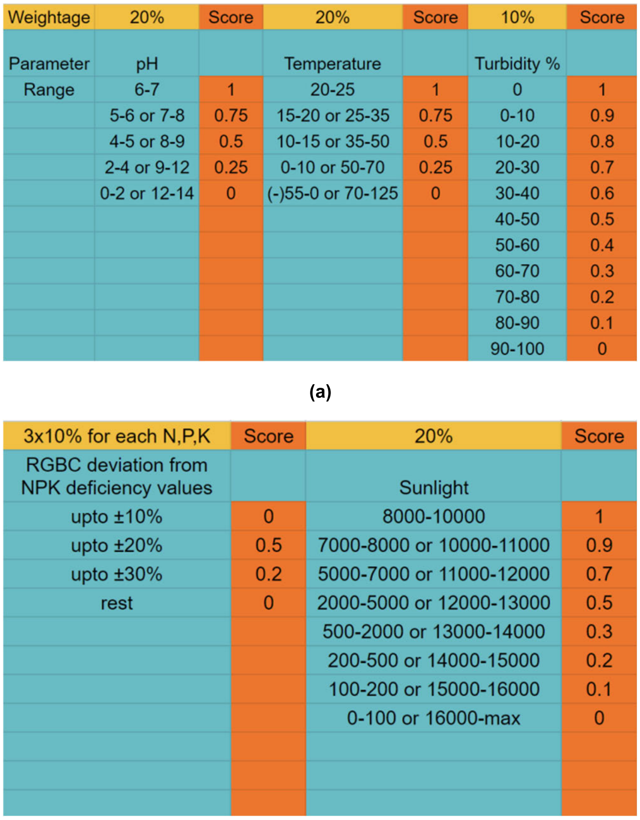


(a)

(b)

FIGURE 4. Basic software methodology flowchart for (a) sensor-hub and (b) image-server.

levels (R, G, B, and C), and light intensity (LUX) to calculate the healthiness score.



Weightage	20%	Score	20%	Score	10%	Score
Parameter	pH		Temperature		Turbidity %	
Range	6-7	1	20-25	1	0	1
	5-6 or 7-8	0.75	15-20 or 25-35	0.75	0-10	0.9
	4-5 or 8-9	0.5	10-15 or 35-50	0.5	10-20	0.8
	2-4 or 9-12	0.25	0-10 or 50-70	0.25	20-30	0.7
	0-2 or 12-14	0	(-)55-0 or 70-125	0	30-40	0.6
					40-50	0.5
					50-60	0.4
					60-70	0.3
					70-80	0.2
					80-90	0.1
					90-100	0

(a)

3x10% for each N,P,K	Score	20%	Score
RGBC deviation from NPK deficiency values		Sunlight	
upto ±10%	0	8000-10000	1
upto ±20%	0.5	7000-8000 or 10000-11000	0.9
upto ±30%	0.2	5000-7000 or 11000-12000	0.7
rest	0	2000-5000 or 12000-13000	0.5
		500-2000 or 13000-14000	0.3
		200-500 or 14000-15000	0.2
		100-200 or 15000-16000	0.1
		0-100 or 16000-max	0

(b)

FIGURE 5. **Weightage and Range of Parameters deviation for each component of Healthiness Score.**

The 'HealthinessScore' is computed using the weighted average of the scores obtained for each parameter. The function FindHealthinessScore() contains different sections of code for calculating the score for each parameter.

$$\begin{aligned} HealthinessScore = {} & (0.2 * Temperature\ Score) \\ & + (0.2 * pH\ Score) \\ & + (0.1 * Turbidity\ Score) \\ & + (0.2 * Sunlight\ Intensity\ Score) \\ & + (0.3 * RGB\ Color\ Deviation\ Score) \end{aligned}$$

In this formula, the overall healthiness score is obtained by multiplying each parameter's score by its corresponding weightage factor (expressed as a decimal value) and then adding the resulting values together. For instance, the temperature score is computed based on a predefined range of temperature values, while the pH score is calculated based on a predefined range of pH values. Similarly, scores for other parameters such as turbidity, RGB color levels, and light intensity are calculated using their respective predefined ranges.

To calculate the HealthinessScore, we first need to determine the weightage of each parameter, as detailed in Figure 5. In this case, the weights of temperature, pH, turbidity, sunlight intensity, and R, G, and B color deviation are 20%, 20%, 10%, 20%, and 3*10%, respectively. Next, we need to obtain the values for each parameter. For temperature, we would measure the temperature of the environment being evaluated. For ph, we would measure the acidity or alkalinity of the environment. For turbidity, we would measure the level of cloudiness or haziness in the water. For sunlight intensity, we would measure the amount of light present in the environment. For R, G, and B color deviation, we would measure the deviation of the colors from the standard values, which can be used to determine N, P, and K deficiencies. Once we have obtained the values for each parameter, we can then apply the weightage to each value and sum them up to obtain the healthiness score.

2) CLOUD PROCESSING METHODOLOGY

In our proposed system, sensor data collection and communication are facilitated through an Internet of Things (IoT) device, specifically an ESP32 microcontroller. Figure 6 illustrates the process by which sensor data is collected and transmitted to the Azure cloud. The ESP32 device interacts with the sensors and sends the collected data to the cloud infrastructure. Within the Azure cloud, the data is stored in the form of blobs. Each time new data is received, it is stored as a blob, ensuring the preservation of chronological information. This data storage mechanism allows for efficient retrieval and processing of sensor data for further analysis and decision-making. In Figure 7, the flowchart for the usage of Azure DataBricks to create a PySpark data-frame and for the conversion of this data-frame to a CSV file is presented.

Figure 8 outlines the subsequent steps involved in data processing and analysis. The sensor data stored as blobs in Azure is retrieved and loaded into a PySpark dataframe, leveraging the capabilities of Databricks. PySpark provides a powerful distributed computing framework for large-scale data processing and analysis. After the data is loaded into the PySpark dataframe, the healthiness score of the plants is calculated based on predefined metrics and algorithms. This score serves as a quantitative indicator of the plants' overall health status. Logistic regression is a supervised learning algorithm used for binary classification tasks, such as predicting plant health in hydroponic farming. It analyzes sensor data to determine the healthiness of plants by transforming input features, such as temperature and nutrient levels, into numerical values. The algorithm establishes a mathematical relationship between these features and a target variable (healthiness score) using a sigmoid function. Coefficients are estimated through iterative optimization algorithms like gradient descent, minimizing the difference between predicted probabilities and actual scores. The model is trained over multiple epochs and evaluated using metrics like accuracy and precision. Logistic regression is a reliable method for predicting plant health in hydroponic systems, aiding in optimizing farming practices for healthy crop growth. The integration between Azure storage and Databricks allows for seamless data transfer and processing.

Algorithm: Finding Optimal Parameters for Logistic Regression in a Hydroponic System

```
Input:
  • X: Feature matrix of size (m x n), where m is the number of samples and n is the number of features.
  • Y: Target vector of size (m x 1), representing the corresponding labels for each sample.
  • learning_rate: The learning rate parameter for gradient descent.
  • num_iterations: The number of iterations for gradient descent.
  • convergence_threshold: The convergence threshold for the difference in cost between iterations.
  • regularization_parameter: The regularization parameter for controlling overfitting.
Output:
theta: The optimal parameter vector of size (n x 1) for logistic regression.
Start
Step 1: Initialize theta as a vector of zeros with size (nx1).
Step 2: Initialize cost difference (diff_cost) with a large value.
Step 3: Initialize iteration counter (iteration) to 0.
Step 4: Compute the initial cost (cost) using the current parameter values:
  • Compute the hypothesis (h) by multiplying X with theta and applying the sigmoid function.
  • Compute the cost function (J) using the log loss formula: $J = (-1/m) * sum(y. * log(h) + (1 - y). * log(1 - h))$
  • Compute the regularization term (reg_term) to prevent overfitting: $reg\_term = (regularization\_parameter/(2 * m)) * sum(theta(2 : end). \wedge 2)$
  • Add the regularization term to the cost function: $J = J + reg\_term$
Step 5: Repeat until convergence or until reaching the maximum number of iterations:
  • Update the iteration counter: $iteration = iteration + 1$
  • Compute the gradient (grad) of the cost function with respect to theta: $grad = (1/m) * X' * (h - y) + (regularization\_parameter/m) * [0; theta(2 : end)]$
  • Update theta using gradient descent: $theta = theta - learning\_rate * grad$
  • Compute the new cost (new_cost) using the updated parameter values:
      ▪ Compute the new hypothesis (new_h) by multiplying X with the updated theta and applying the sigmoid function.
      ▪ Compute the new cost function (new_J) using the log loss formula: $new\_J = (-1/m) * sum(y. * log(new\_h) + (1 - y). * log(1 - new\_h))$
      ▪ Compute the regularization term (new_reg_term) with the updated theta: $new\_reg\_term = (regularization\_parameter/(2 * m)) * sum(theta(2 : end). \wedge 2)$
      ▪ Add the regularization term to the new cost function: $new\_J = new\_J + new\_reg\_term$
  • Compute the difference in cost between the new and previous iterations: $diff\_cost = abs(J - new\_J)$
  • Update the cost to the new cost: $J = new\_J$
  • If the difference in cost is below the convergence threshold or the maximum number of iterations is reached, exit the loop.
Step 6: Return theta as the optimal parameter vector.
End
```

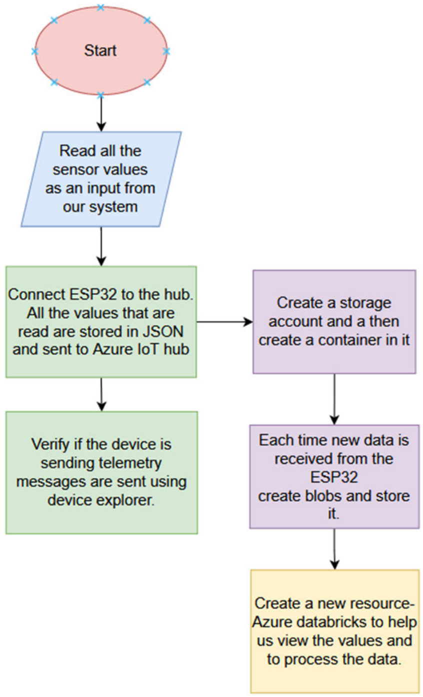


FIGURE 6. Flowchart for cloud processing methodology.

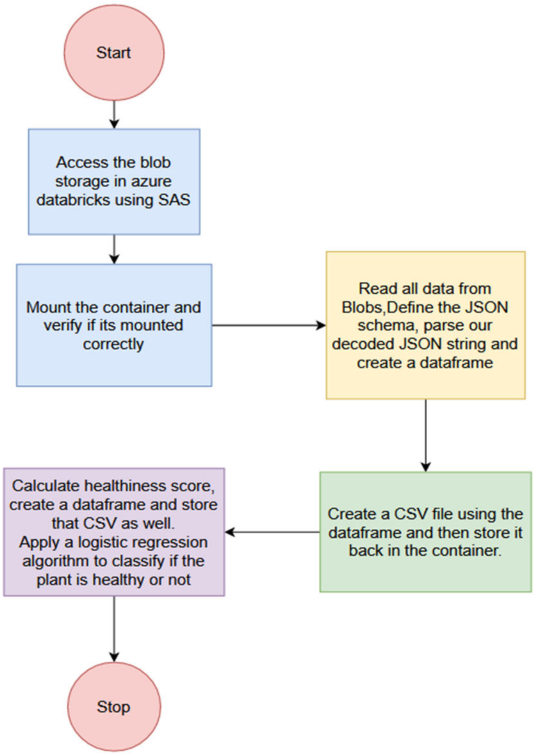


FIGURE 7. Flowchart for usage of Azure DataBricks services.

Azure storage provides a reliable and scalable storage solution, while Databricks facilitates efficient data analysis and machine learning computations. This cloud-based approach offers the flexibility and computational power required for processing large volumes of sensor data and deriving meaningful insights for plant health monitoring. The points mentioned below in Figure 8 highlight the algorithm for

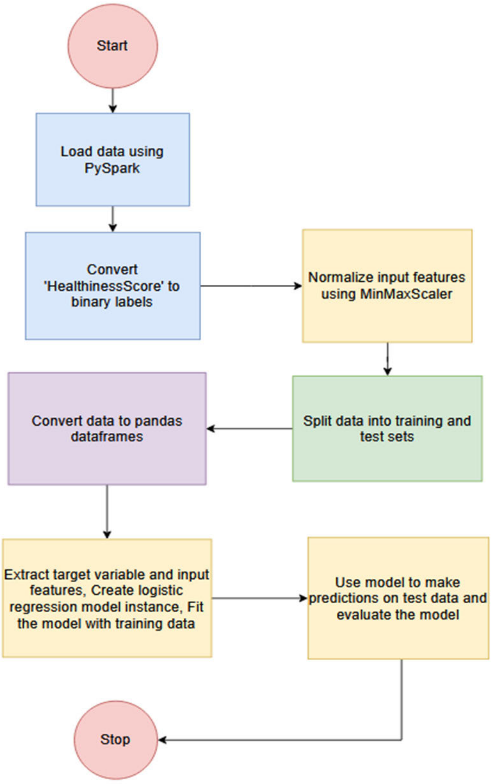


FIGURE 8. Flowchart for machine learning methodology.

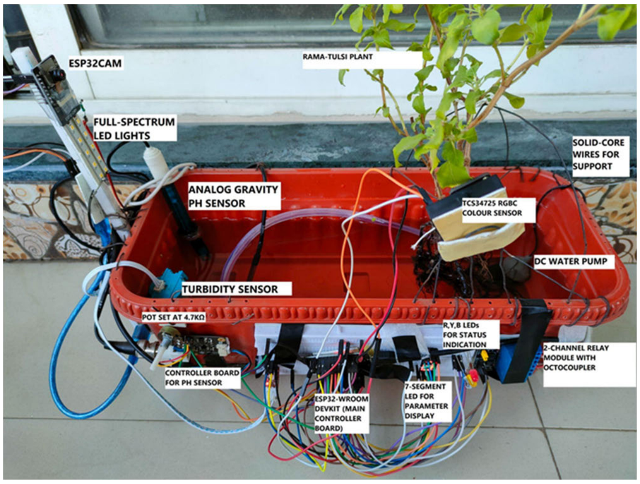


FIGURE 9. Image of hardware setup for hydroponic cultivation of Holy-Basil (with annotations).

estimating the optimal parameters for the logistic regression model in the proposed Hydroponics System.

IV. RESULTS AND DISCUSSION

A. HARDWARE SETUP OF IoT AND ML BASED HYDROPONICS SYSTEM

This research work develops an AI-enabled hydroponic system to cultivate exotic and therapeutic plants. Logistic regression on sensor data classifies seasonal elements, including nutrient dispensation, water stream, and light, for optimal plant growth. The system used the ESP32S chipset and a 2MP camera module to take plant photographs. The decision tree identified plant N, P, and K shortages from sensor data. For the purpose of this investigation, a medicinal plant called Rama Tulsi (Holy Basil), which is well-known for its curative qualities, was selected as the plant of choice. The system's hardware shown in Figure 9 comprised the ESP32-CAM for taking pictures, the ESP32-WROOM DEV module for data processing, the TCS34725 RGB color sensor, the DS18B20 temperature sensor, the water turbidity Sensor, and the DFRobot gravity analogue pH sensor. Submersible water pumps circulated water in the hydroponic system.

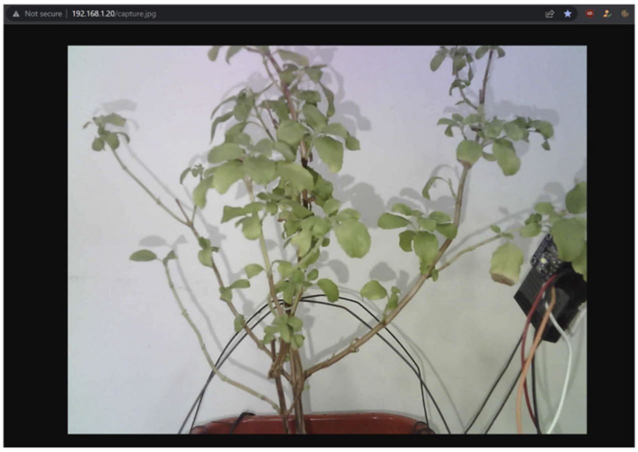


FIGURE 10. Display of the captured image from the OV2640 camera of the ESP32-CAM through the local-IP image-server.

B. SCREENSHOTS FROM IDE OF IMAGE SERVER AND SENSOR-HUB

The proposed system successfully automates the monitoring of the growth environment and output parameter control, increasing the yields and health of exotic and therapeutic plants. The use of this hydroponic system proves its effectiveness. The system provided real-time hydroponic environmental monitoring and plant-specific settings. The cloud's assessments of sensor data regarding optimal parameters permitted early plant disease detection. The hydroponic system had a monitoring gateway for remote control. The system can be expanded to incorporate more plants and tested over a longer period of time.

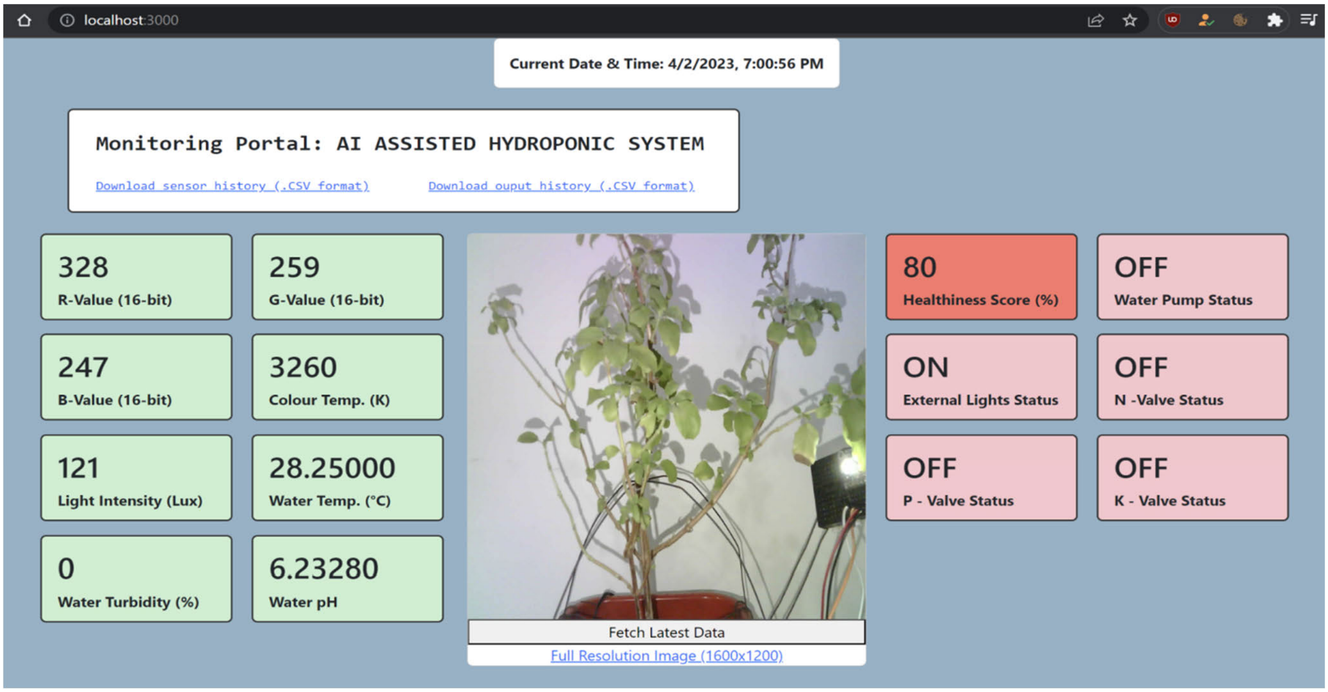
Figure 10 displays the captured image from the OV2640 camera of the ESP32-CAM whenever the page gets refreshed. The fresh images are taken with the built-in LED light on the ESP32-CAM. The image, when accessed through the local IP (i.e., http://192.168.1.20/capture.jpg in this case), provides us with a full-resolution image with 1600 pixels horizontally and 1200 pixels vertically.

Figure 11 demonstrates the successful flashing of the ESP32-WROOM with the code, establishing seamless communication with the connected computer. Wi-Fi and all input and output devices have been properly initialized, facilitating

Message (Enter to send message to 'DOIT ESP32 DEVKIT V1' on 'COM8')

```
Connecting to WiFi...
WiFi Connected Successfully...
TCS3472 found...
DS18B20 found... Initial Temperature: 28.50
{"R":521,"G":403,"B":389,"CLEAR":746,"COLORTEMP":3087,"LUX":182,"TEMP":28.5,"TURBIDITY%":0,"PH":6.339980602}
ThingSpeak Channel update successful...
HTTP code: 204
{"R":417,"G":322,"B":311,"CLEAR":580,"COLORTEMP":2981,"LUX":145,"TEMP":28.375,"TURBIDITY%":0,"PH":6.248405457}
ThingSpeak Channel update successful...
HTTP code: 204
{"R":406,"G":317,"B":305,"CLEAR":604,"COLORTEMP":3217,"LUX":145,"TEMP":28.375,"TURBIDITY%":0,"PH":6.225342274}
ThingSpeak Channel update successful...
HTTP code: 204
```

FIGURE 11. Serial monitor output of the sensor-hub.



Current Date & Time: 4/2/2023, 7:00:56 PM

Monitoring Portal: AI ASSISTED HYDROPONIC SYSTEM

Download sensor history (.CSV format)
Download ouput history (.CSV format)

328 R-Value (16-bit)
259 G-Value (16-bit)
247 B-Value (16-bit)
3260 Colour Temp. (K)
121 Light Intensity (Lux)
28.25000 Water Temp. (°C)
0 Water Turbidity (%)
6.23280 Water pH
80 Healthiness Score (%)
OFF Water Pump Status
ON External Lights Status
OFF N -Valve Status
OFF P - Valve Status
OFF K - Valve Status

FIGURE 12. Screenshot of the React-based monitoring portal.

the successful transmission of the JSON string to the Azure IoT-Hub for storage and modeling objectives.

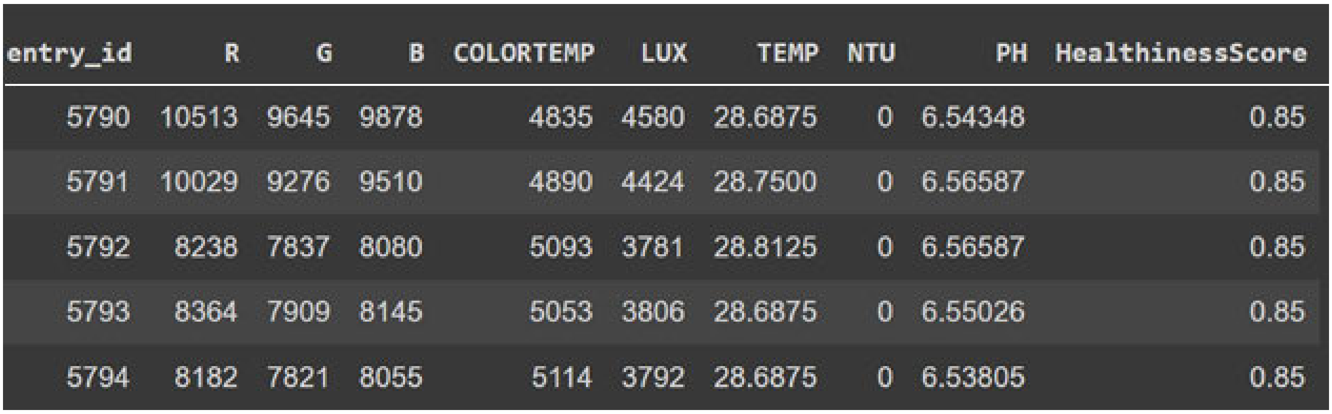
C. SCREENSHOTS OF THE REACT-BASED MONITORING PORTAL

Figure 12 shows a react-based monitoring portal that is written in JavaScript, HTML, and CSS. The monitoring portal shows all the necessary information about the plant.

- The boxes in green on the left side show the sensor data that is sent to the cloud from the sensor-hub.
- The boxes in red on the right side show the parameters calculated in the cloud after processing the data from the sensors and sending it to the sensor-hub to operate the valves, lights, and pump.
- The middle section shows the current image of the plant along with buttons to re-capture the latest image and data and to see the image in full resolution.
- The top portion shows the current data and time, as well as links to download the sensor and output history in CSV format.

D. SCREENSHOTS FROM AZURE IoT-HUB AND DATA BRICKS WITH HEALTHINESS SCORE PREDICTION

In Figure 13, the newly created CSV file is displayed, showing the last 5 entries. The CSV has undergone data processing,

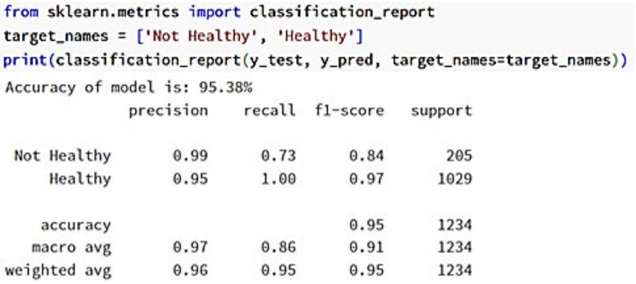


entry_id	R	G	B	COLORTEMP	LUX	TEMP	NTU	PH	HealthinessScore
5790	10513	9645	9878	4835	4580	28.6875	0	6.54348	0.85
5791	10029	9276	9510	4890	4424	28.7500	0	6.56587	0.85
5792	8238	7837	8080	5093	3781	28.8125	0	6.56587	0.85
5793	8364	7909	8145	5053	3806	28.6875	0	6.55026	0.85
5794	8182	7821	8055	5114	3792	28.6875	0	6.53805	0.85

FIGURE 13. Last few entries of calculated healthiness score.

TABLE 4. Comparison of proposed system with other intelligence based hydroponics system.

Type of Cultivation	Adopted Intelligence Technique	Accuracy (%)	Precision (%)	Recall (%)	F-Measure (%)	Reference
Hydroponics	CNN	85	92	78	84	[5]
Hydroponics	IoT	78	80	75	77	[10]
Hydroponics	IoT	92	87	94	90	[6]
Fully Automated Hydroponics	**IoT & ML**	**95**	**96**	**95**	**95**	**Proposed System**



```
from sklearn.metrics import classification_report
target_names = ['Not Healthy', 'Healthy']
print(classification_report(y_test, y_pred, target_names=target_names))
Accuracy of model is: 95.38%
              precision    recall  f1-score   support

 Not Healthy       0.99      0.73      0.84       205
     Healthy       0.95      1.00      0.97      1029

    accuracy                           0.95      1234
   macro avg       0.97      0.86      0.91      1234
weighted avg       0.96      0.95      0.95      1234
```

FIGURE 14. Accuracy of the machine learning model.

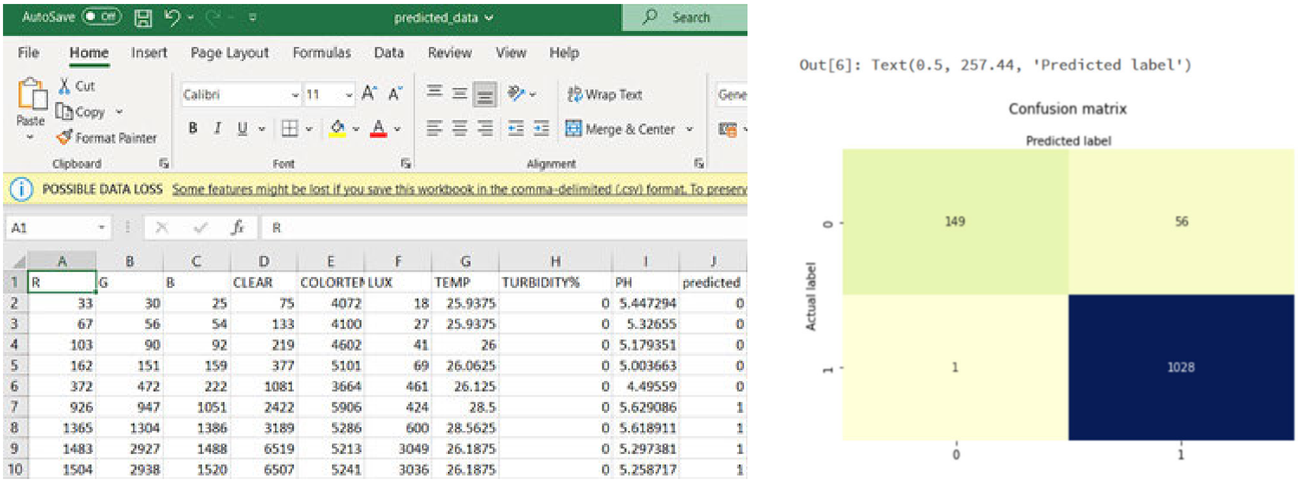
resulting in a total count of 5794 entries. Notably, a column titled ‘HealthinessScore’ has been added, which now includes the calculated Healthiness Score for each entry. The HealthinessScore displayed in the React-based monitoring portal earlier was ‘80’, but it has achieved a score of ‘85’ after some time, which is due to parameter optimization through the proposed hydroponics system.

From Figure 14, it is well observed that the accuracy of our proposed model is based on various parameters like precision, recall, F1-score, and support. Precision is a proportion of true positives among the total predicted positive samples; F1-score is the harmonic mean of precision and recall; recall is how many of the positive samples the classifier correctly identified; and support measures the number of samples that belong to a particular class in the dataset. Figure 15 (a) shows the CSV file depicting the classification carried out by our model for a set of input sensor data and test data that we provided. Figure 15 (b) represents the confusion matrix, which represents four entries, namely True Positive (TP-11), False Positive (FP-01), False Negative (FN-00), and True Negative (TN-10). In this case, 11- would represent when the model predicted the plant to be healthy and it was a correct prediction. 01- would represent the plant was unhealthy but it predicted the plant to be healthy, 00- would represent the plant was healthy but it predicted it to be unhealthy, and 10- would represent the plant was unhealthy and the prediction was correct. Azure DataBricks provides users with the option to set the interval or schedule for data processing and get alerts. Users are able to set the appropriate intervals between data processing and receive timely notifications as a result of this feature’s availability.

E. COMPARISON AND COST ANALYSIS

To the best of our knowledge, very few studies have been reported on the real-time use case of a fully automated hydroponics system. In Table 4, the proposed system is compared with similar work in the literature and has shown better performance metrics, with 95% validation accuracy and an F-measure of 95%.

The total estimate of the AI-enabled hydroponic system proposed for the cultivation of Holy Basil plant is about 60 USD or 4,700 INR. The most expensive component is the pH sensor, which costs about 20 USD or 1,650 INR.



POSSIBLE DATA LOSS Some features might be lost if you save this workbook in the comma-delimited (.csv) format. To preserv

	A	B	C	D	E	F	G	H	I	J
1	R	G	B	CLEAR	COLORTEI	LUX	TEMP	TURBIDITY%	PH	predicted
2	33	30	25	75	4072	18	25.9375	0	5.447294	0
3	67	56	54	133	4100	27	25.9375	0	5.32655	0
4	103	90	92	219	4602	41	26	0	5.179351	0
5	162	151	159	377	5101	69	26.0625	0	5.003663	0
6	372	472	222	1081	3664	461	26.125	0	4.49559	0
7	926	947	1051	2422	5906	424	28.5	0	5.629086	1
8	1365	1304	1386	3189	5286	600	28.5625	0	5.618911	1
9	1483	2927	1488	6519	5213	3049	26.1875	0	5.297381	1
10	1504	2938	1520	6507	5241	3036	26.1875	0	5.258717	1

```
Out[6]: Text(0.5, 257.44, 'Predicted label')
```

(a)

(b)

FIGURE 15. **(a) CSV file containing the prediction column for the process that completed testing and validation (b) Confusion matrix obtained after machine learning.**

The least expensive component is the DS18B20 waterproof temperature sensor, which costs 1.35 USD or 110 INR. Other components such as the ESP32-CAM, ESP32-WROOM, FTDI programmer, turbidity sensor, TCS34725 RGB color sensor, sample plants and tray, hydroponic nutrients, and DC submersible pump with tubing contribute to the overall cost of the project.

For future costs, the project will require maintenance and replacement of components as needed. The hydroponic nutrients will need to be replenished periodically, and the plants will need to be replaced after each growing cycle. Additionally, if the system is expanded, more sensors and components may be needed, which would increase the cost of the project by 30%. However, the benefits of using such an efficient hydroponic system will lead to improved plant growth, increased yield, and reduced water consumption, making it a cost-effective solution in the long run.

V. CONCLUSION

The proposed Hydroponics System is an IoT-based system optimized for Holy Basil (Ocimum Tenuiflorum) plant growth. It uses ML algorithms like logistic regression and decision trees to adjust parameters for optimal growth, resulting in the reduction of manual monitoring. The system includes sensors for temperature, humidity, RGB color composition, and pH levels, valves for N, P, and K nutrient dispensing control, LED indicators, and a web-based remote monitoring portal. The integration of cloud technology plays a crucial role in decision-making within the AI-enabled Hydroponics System. The system leverages the power of cloud computing to store and process large amounts of data collected from the sensors. Through cloud connectivity, the system can access advanced analytics and machine learning models, enabling it to make informed decisions based on the analyzed data. This cloud-based approach enhances the system's capabilities and flexibility, allowing for efficient and remote monitoring of plant health as well as providing a platform for continuous system improvement through data analysis.

The prototype of the proposed system heavily relies on historical data, which may affect accuracy when faced with new scenarios. Hardware constraints and the need for human intervention in complex situations pose challenges. The system's scalability and adaptability to different setups and plant

TABLE 5. **Abbreviations and their full-forms.**

Abbreviation	Full-Form
N, P, K	Nitrogen, Phosphorous, Potassium
AI	Artificial Intelligence
Wi-Fi	Wireless Fidelity
IoT	Internet of Things
ML	Machine Learning
MP	Mega-Pixels
RGB	Red, Green, Blue
LED	Light Emitting Diode
IDE	Integrated Development Environment
JSON	JavaScript Object Notation
NFT	Nutrient Film Technique
DWC	Deep Water Culture
IP	Internet Protocol
NTU	Nephelometric Turbidity Unit

species may require modifications. Regular maintenance and calibration are essential for reliable performance. Addressing these limitations can enhance the system's capabilities in hydroponic agriculture. Overall, the proposed research shows the potential of IoT and ML in improving the efficiency and effectiveness of hydroponic systems. By utilizing the ML algorithms to adjust the parameters according to the plant's needs, the system is able to optimize the growth of exotic and medicinal plants. Our work has major implications for the agriculture industry, especially in areas where traditional farming may not be feasible or sustainable. The suggested intelligence system also reduces the need for manual monitoring and intervention, reducing labor costs and increasing accuracy to 95% compared to other similar works reported.

APPENDIX

See Table 5.

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