Hydroponics For Sustainable Farming of Future

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Abstract— This study focuses on designing and implementing an IoT-based hydroponic system tailored for exotic and medicinal plants. It leverages Azure IoT Hub, Azure Container, and Azure Data Bricks to apply logistic regression on sensor data, predicting seasonal parameters like nutrient dispensation, water flow, and light for optimal growth. Cloud decision-making identifies potential N, P, and K deficiencies, calculating a 'Healthiness Score'. ESP32S-based main boards with built-in Wi-Fi, Bluetooth, and a high-resolution camera capture plant images. A React-based portal allows remote monitoring. Rama Tulsi (Holy Basil) is the chosen plant, known for its medicinal properties. This system aims to enhance growth efficiency, reduce manual monitoring, and recycle water efficiently, checking for contamination before use. It shortens time from field to market, requiring minimal space compared to traditional methods.

Index Terms— Hydroponics, Internet of Things, holy-basilplants, machine leaning (ML), healthiness score.

I. INTRODUCTION

Hydroponics is the practice of growing plants without the use of soil, and it incorporates the process of growing crops with the use of mineral fertilizer solutions in an aqueous solvent. As the name implies, hydroponics is a subset of hydroculture. This system nurtures quicker growth, much stronger yields, and supreme quality. Over the past years, farming in urban areas has gained a lot of recognition since it helps maintain a healthier and better lifestyle. In the conventional method of farming, many difficulties are faced, like plowing, weeding, pests, and climate. Not only that, soil-based agriculture introduces some soil-based crop diseases and also requires large amounts of land.[1]

In this context as a major key element, various sensors are used to measure the different environmental factors favourable for the growth of a plant such as the light intensity, temperature, hydrogen-ion activity in water- based solutions and thereby displaying the acidity or alkalinity reading expressed as PH. Agriculture is the cornerstone of human civilization and is responsible for the production of quality food for the human population . To ensure the availability of inexpensive and quality products to meet the increasing food demand, intensification of the growing practices is necessary. By definition, hydroponics is subset of hydro culture.[2]

Hence, the method of hydroponics is much more convenient nowadays, as it decreases the burdensome physical labor of the farmers. The significance of hydroponics is to provide a way for one to grow their own food without the need for soil, particularly for those who live in urban settlements. Accurate pH level, air temperature, relative humidity, nutrient level of water, and correct irrigation of water are very important in hydroponics. Thus, a management system that can monitor

these factors is valuable, and it will also ensure a higher success and efficiency rate of yield. With the advancement of technology, we can use emerging technologies like the Internet of Things (IoT) to manage all the factors that are required in a hydroponics system.[3]

A smart and modular hydroponic system is one that makes use of advanced technology to automatically monitor and 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.[4]

II. LITREATURE 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].

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].

III. PROPOSED WORK

Hydroponics, unlike traditional farming, does not require soil to grow food. In this technique, plants are grown either on natural or man-made substrates, where the roots easily extract the nutrients from a prepared nutrient solution. There are different methods for growing food using hydroponics, and their application depends on the specific plant, local climate, and budget, among other factors. Most systems comprise a storage tank for the nutrient solution and an aerator, as illustrated in Fig 1.

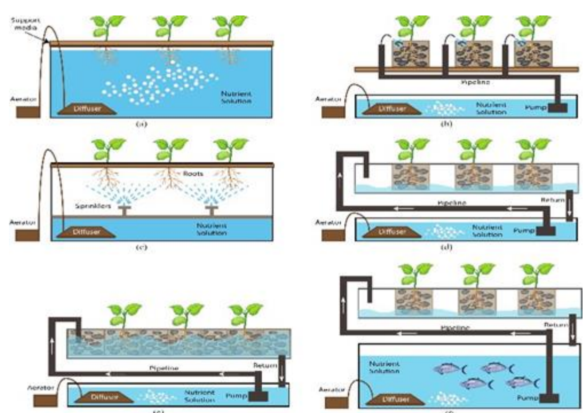


Fig 1. Different types of hydroponic systems

Floating Root System or Deep Water Culture (DWC)
In this system, the root of the plant is immersed in the nutrient solution, while the rest of it is supported above water level using polystyrene, cork bark or wood, among other materials .

Drip Irrigation
This method is best suited for tomato and pepper-like crops. In this case, the nutrient solution is pumped directly to the roots of the plants with regulated flow. The solution is administered at predetermined time intervals and, for closed systems, the leftover solution is returned to the storage tank.

Aeroponics
Tubers and roots are ideal to grow using aeroponics. In this configuration, the plants, with their roots hanging down in the air, get their nutrients from periodic spraying by a system of sprinkles. The main advantage of this technique is that it does not require an airing system as oxygen is carried along with the sprayed nutrient solution.

Nutrient Film Technique
This method, also known as NFT, is like the floating root system, except that the plant roots are not completely submerged in the nourishing solution, but in a liquid stream flowing through a piping system. Although NFT requires smaller amounts of nutrient solution than the floating root system, it requires additional energy and components to operate. The excess solution returns to the storage tank by gravity and the flow of nutrient solution can be continuous or periodic

Ebb and Flow
Plants are placed in a tray, which is periodically filled with nutrient-rich water pumped from a reservoir below. The system uses gravity to return the water to the reservoir and reuse.

Aquaponics
This technique exploits the symbiosis of flora and fauna to achieve an efficient system in which fish feces afford the nutritional requirements of the plants. The absorption of nutrients by plants, combined with the microbial process of nitrification and denitrification, allows the recycling of water from the fish tank, forming a balanced micro- ecosystem .

A. HARDWARE METHODOLOGY

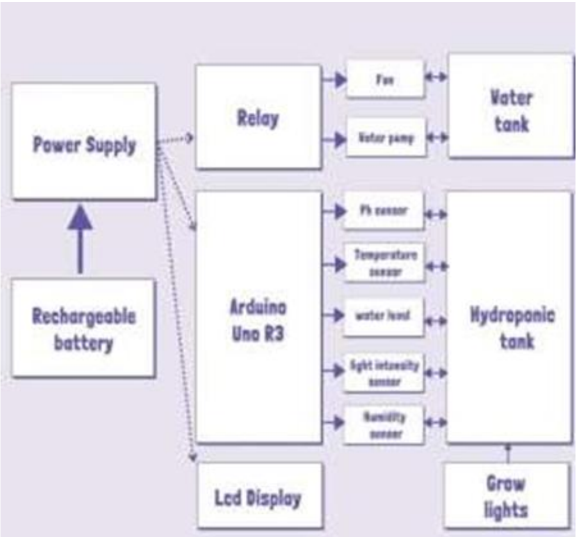
- Setting up the Hardware: Assembling the ESP32CAM microcontroller and attaching the input sensors (DS18B20,TCS34725,TurbiditySensor,andDFRobot Gravity Analogue PH sensor) and output hardware (DC water pump, LED and buzzer status indicators, valves for nutrient flow) to the system.
- Programming the 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 ESP32CAM 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.

B. 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.

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.

IV. METHODOLOGY



In continuous-flow solution culture, the nutrient solution constantly flows past the roots. It is much easier to automate than the static solution culture because sampling and adjustments to the temperature and nutrient concentrations can be made in a large storage tank that has potential to serve thousands of plants. A popular variation in the nutrient film technique or NFT, whereby a very shallow stream of water containing all the dissolved nutrients required for plant growth is recirculated past the bare roots of plants in a watertight thick root mat, which develops in the bottom of the channel and has an upper surface that, although moist, is in the air, Subsequent to this, an abundant supply of oxygen is provided to the roots of the plants. As a general guide, flow rates for each gully should be 1 litre per minute. At planning, rates may be half this and the upper limit of 2L/min appears about the maximum. Flow rates beyond these extremes are often associated with nutritional problems. Depressed growth rates of many crops have been observed when channels exceed 12 meters in length. According to studies while oxygen level has been remaining adequate, nitrogen may be depleted over the length of the gully. As a consequence, channel length should not exceed 10-15- meter length. In situations where it is not possible, the reductions in growth can be eliminated by placing another nutrient feed halfway along the gully and having the flow rates through each outlet.

5.1 HARDWARE REQUIREMENTS:

The most common type set of requirements defined by any operating system or software application is the physical computer resources also known as hardware. The hardware requirement list is:

5.1.1 BATTERY

Fig 1: Battery

A battery is a device consisting of one or more electrochemical cells that convert stored chemical energy into electrical energy. In simpler terms, it's a device that stores energy in a chemical form and releases it as electrical energy when needed.

5.1.2 SOIL MOISTURE SENSOR

Fig 2 : SOIL MOISTURE SENSOR

Soil moisture sensors measure the volumetric water content in soil. Since the direct gravimetric measurement of free soil moisture requires removing, drying, and weighing of a sample, soil moisture sensors measure the volumetric water content indirectly by using some other property of the soil, such as electrical resistance, dielectric constant, or interaction with neutrons, as a proxy for the moisture content.

5.1.3 GROW LIGHTS

Fig 3: GROW LIGHTS

Grow lights are artificial light sources designed to stimulate plant growth by emitting specific wavelengths and intensities of light that plants need for photosynthesis. These lights are particularly useful in environments where natural sunlight is insufficient or unavailable, such as indoor cultivation, greenhouse operations, or supplemental lighting in outdoor settings.

5.1.4 WATER PUMP

Fig 4 : WATERPUMP

The water pump pushes coolant from the radiator through the coolant system, into the engine and back around to the radiator. The heat that the coolant picked up from the engine is transferred to the air at the radiator. Without the water pump, the coolant just sits in the system.

5.1.5 PH SENSOR

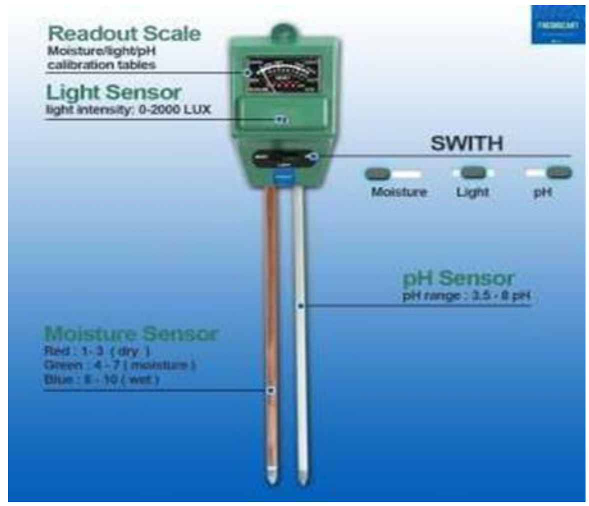


Fig 5 : PH SENSOR

A ph sensor is one of the most essential tools that'stypically used for water measurements. This type of sensor is able to measure the amount of alkalinity and acidity in water and other solutions. pH stands for the power of hydrogen, and it is calculated based on the number of hydrogen ions in a liquid. Because these hydrogen ions create a positive charge, an acidic solution with many hydrogen ions can easily conduct an electric current. pH meters measure that ability.

5.1.6 LDR 5mm – Photo Cell

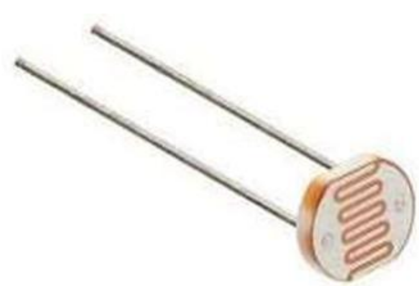


Fig 6 : LDR 5mm – Photo Cell

A photoresistor (also known as a photocell, or light-dependent resistor, LDR, or photo- conductive cell) is a passive component that decreases in resistance as a result of increasing luminosity (light) on its sensitive surface, in other words, it exhibits photoconductivity. A photoresistor can be used in light-sensitive detector circuits and light-activated and dark-activated switching circuits acting as a semiconductor resistance.

In the dark, a photoresistor can have a resistance as high as several megaohms (MΩ), while in the light, it can have a resistance as low as a few hundred ohms. If incident light on a photoresistor exceeds a certain frequency, photons absorbed by the semiconductor give bound electrons enough energy to jump into the conduction band.

5.1.7 Humidity Sensor

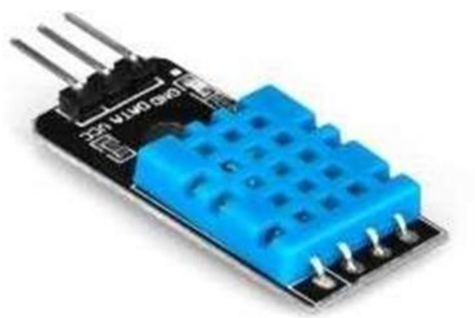


Fig 7 : Humidity Sensor

A humidity sensor (or hygrometer) senses, measures, and reports both moisture and air temperature. The ratio of moisture in the air to the highest amount of moisture at a particular air temperature is called relative humidity. Relative humidity becomes an important factor when looking for comfort.

5.2 SOFTWARE REQUIREMENTS

The software requirements are description of features and functionalities of the system. The software requirement is a field within software engineering that deals with establishing the needs of stakeholders that are to be solved by software.

Requirements convey the expectations of users from the software product. The software requirement list is:

5.2.1 : Internet of Things (IOT)

Fig 5.2.1 Internet of Things (IOT)

IOT is an umbrella term that refers to the billions of physical objects or “things” connected to the Internet, all collecting and exchanging data with other devices and systems over the Internet. While IOT has been in existence since the 90s, recent advances in a number of different technologies have made it more practical, such as:

- Access to affordable and reliable sensors
- Increase in the availability of cloud computing platforms
- Advances in machine learning and AI technologies.

IOT devices can range from small ordinary household cooking appliances to sophisticated industrial tools. Each IOT component has a Unique Identifier (UID) and they can also transmit data without the assistance of humans IOT networks can be categorized into four main types: LAN/PAN, LPWAN, and Mesh protocols. The classification is based on factors like network coverage and available bandwidth. It's worth noting that the majority of IOT networks operate wirelessly.

Raspberry Pi is adept at executing flight control algorithms and acting as an autopilot system. It processes data from onboard sensors, such as accelerometers, gyroscopes, and GPS modules, contributing to stable flight and autonomous maneuvering. Beyond flight control, Raspberry Pi's computational power is harnessed for real-time data processing during flight. Drones equipped with cameras or other sensors leverage Raspberry Pi to perform tasks like image recognition, object tracking, and environmental monitoring. This capability is particularly valuable in diverse applications such as aerial surveying, precision agriculture, and search and rescue operations. Additionally, Raspberry Pi facilitates seamless communication between the drone and the ground station, transmitting telemetry data for monitoring the drone's status and enabling remote control.

5.2.2 : Machine learning

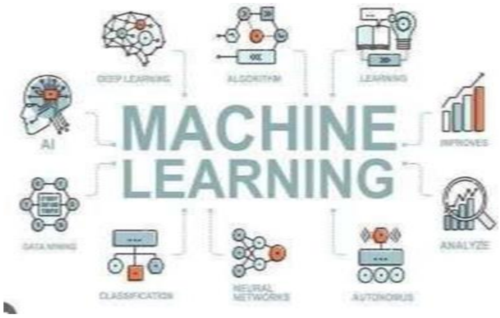


Fig 5.2.2Machine learning

Machine learning (ML) is a field of study in artificial intelligence concerned with the development and study of statistical algorithms that can learn from data and generalize to unseen data, and thus perform tasks without explicit instructions. Recently, generative artificial neural networks have been able to surpass many previous approaches in performance.

Machine learning approaches have been applied to large language models, computer vision, speech recognition, email filtering, agriculture, and medicine, where it is too costly to develop algorithms to perform the needed tasks.[4][5] ML is known in its application across business problems under the name predictive analytics. Although not all machine learning is statistically based, computational statistics is an important source of the field's methods.

The mathematical foundations of ML are provided by mathematical optimization (mathematical programming) methods. Data mining is a related (parallel) field of study, focusing on exploratory data analysis through unsupervised learning.[7][8] From a theoretical point of view Probably approximately correct learning provides a framework for describing machine learning.

CONCLUSION AND FUTURE SCOPE

Progress has been rapid and results obtained in various countries have proved that this technology is thoroughly practical and has very definite advantages over conventional methods of crop production. The main advantages of soil- less cultivation is the much higher crop yields. People living in crowded city streets, without gardens, can grow fresh vegetables and barren and sterile areas can be made productive at relatively low cost. Our designed system achieved to produce plants/crops in an efficient way by reducing the usage of water, nutrients and area required for farming.

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