Automated Hydroponics for Agricultural Applications

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***Abstract*—Food shortages and population expansion are some major issues faced in recent times. As a result, many countries struggle to provide food for their citizens. This is mostly due to the fact that food production does not expand in proportion to the growing population. Some of the causes for this are a lack of available land space, pollution, climate change, and so on. In this scenario, hydroponics is a much-preferred alternative for agriculture. It does not need soil for agriculture but uses water as a medium to grow crops. Smart farming technologies help farms more intelligently perceive their vital components. A hydroponics system may be used to raise vegetables and other nutritious crops. But various parameters like pH, nutrient level, and temperature must be strictly monitored and maintained for the healthy growth of crops. Nutrient mixing is a crucial system component that directly affects plant development. With the use of specialized sensors, the IoT-based hydroponics monitoring system has the ability to track pH value, temperature, humidity level, and water level. After those values have been obtained, they are displayed on a liquid crystal display and a mobile application via the Internet of Things.**

The recommended automated solution would do away with the drawbacks of the existing approach. Long-term data gathering may improve accurate reckoning. Many Sustainable Development Goals (SDGs) are met by this initiative, including eradicating hunger and poverty and creating sustainable towns and cities.

Keywords—Hydroponics, Automation, Nutrient Film Technique, Ebb and Flow technique Agriculture, Sustainable Development Goals

I. INTRODUCTION

Agriculture is the backbone of human society, and hydroponics is a technique used to produce plants in a non-soil medium or directly in a nutrient-rich water-based solution. The Internet of Things (IoT) is a new field that integrates consumer products, durable goods, cars and trucks, industrial and utility components, sensors, and other everyday things and is significant from a technological, social, and economic perspective. Automation has changed the way we work, live, and construct things, but it can be expensive to upgrade and maintain. By 2025, there will be 100 billion connected IoT devices and a global economic effect of $11 trillion[1]. Conventional agriculture is unsustainable since it uses 70% of the water that is used for production. In order to accommodate the anticipated needs of the world's population, 38% of the planet's non-frozen territory would need to be converted into agricultural land. This perspective puts many important ecosystems at risk of extinction, particularly those that are crucial to preserving the already unbalanced levels of carbon dioxide in our atmosphere. Many of the drawbacks of the agricultural issues that are currently plaguing our globe can be addressed with hydroponic gardening. Because of the straightforward yet efficient design, hydroponic growers prefer the nutrient film technique system (NFT system). This technique which is comparable to the Ebb and Flow technique[12] employs water pumps to provide nutrients to plants, but, unlike the flood and drain mechanics of an Ebb and Flow arrangement, the NFT system is a continuously flowing one. Smaller and more quickly growing plants, such as lettuce, herbs, baby greens, and strawberries, are grown in it. An NFT system can be designed in a number of different ways, but they all follow the model of a very shallow nutritional solution poured down the tube.

The major goal of this work is to create a hydroponics monitoring system based on the IoT that continually measures and shows the user data on variables like pH level, water level, humidity, temperature, dissolved solids, and more. Sensors are the hardware elements that are utilized for transferring and receiving data using the IoT. By easily monitoring and maintaining the system parameters for efficient plant development, the implementation of IoT in hydroponics systems might bring about amazing advances in the agricultural sector. The Wi-Fi-enabled system can be connected to the internet, where a data server saved system parameter values including pH, temperature, and humidity in a database and gave the data to a web application for user access. Through the use of the IoT application in the hydroponics monitoring system, the values of system parameters and information may be shown on the web application in real time. Solar energy and water recycling are used as renewable energy sources to safeguard the environment, making it environmentally sound. Also, the cultivated vegetable items are organic and safe to eat.

II. Literature Survey

Hydroponics, or soilless cultivation [1], has been widely used in different countries because of its feasibility and environmental sustainability. In locations where there are significant soil and water difficulties, such as soil-borne pests and illnesses, salinity in soil and water, chemical residues in soil and water, and a shortage of water supply, this technique can be regarded as the best alternative. In hydroponics, the right amount of nutrients is directly added to the water to grow plants.

Crops are grown in hydroponics without depending on soil for nutrient absorption and stability; instead, nutrients from the earth are delivered straight to the crops through a water reservoir. The sufficient nutrients required by the plants are measured and fed to the water reservoir, ensuring that the crops receive the same amount of nutrients from the water as they do from the soil[2]. This entire hydroponic system can be automated with the help of IoT. Data from the hydroponic system is transferred to the cloud for accurate automation. The health of the crops is constantly checked with the use of data obtained by sensors and actuators[3]. There have been researches that use similar ideas. Similar to hydroponics, aquaponics [4]is a method of sustainable agriculture where fish excreta is used as a nutrient supply for plants. A symbiotic environment [5] is created in this system even though this method can be complicated to implement using traditional techniques. A collection of sensors is used for monitoring dissolved oxygen, pH, electrical conductivity, water level, and water temperature, with the goal of boosting urban farming and managing the abiotic state of their system to keep the organism healthy[5]. By making use of fish excreta, the nutrient deficiency of plants can be solved and also reduce human intervention in plant growth [6]. Even if these are studies made based on aquaponic systems, they are very much relevant in hydroponics as both focus on agriculture and sustainability.

The yield and quality of crops grown in hydroponic systems are directly impacted by nutrient composition, electrical conductivity, pH, and oxygen concentration. Crops exhibit signs of stress if any of these factors are not optimal. Nutrient content, pH, EC, temperature, and humidity are just a few of the many factors that must be taken into consideration while using soilless growing techniques. There are several types of vital nutrients [7-9] and specific levels of their concentrations in an aquaponic as well as hydroponic system. The two most important nutrients to consider were ammonium and calcium. In an aquaponic system [7], based on the months in which lettuce was grown, the median value of these nutrients from the historical data set served as the ideal concentration to be kept in the solution to support the healthy growth of fish and lettuce plants in a coupled setup.

The aquaponics system can be made more user-friendly [10], as it may even be utilized for therapeutic reasons by the elderly. As a result, the Internet of Things (IoT) is incorporated into an aquaponics system in this study, which presents a smart green care system (SGCS). The suggested system employs facial recognition technology to record the elderly's work and rehabilitation history, in conjunction with environmental data analysis, to allow automatic control decisions for equipment in conjunction with a voice control system to eliminate the difficulties encountered by the elderly in operating the information system.

All of the methods have a big disadvantage in that they consume too much power since they employ traditional electric power sources. There are several issues [11] that large-scale aquaponics systems encounter, both technically and economically, one of which is high energy usage. Since lighting consumes about three-quarters of this energy, the detailed attention of this work has been centered on growth lights - kinds, particular wavelengths, photoperiod, daily light integral, and switching frequency. As compared to typical illumination, light-emitting diodes [12] with light treatment optimized for certain plant species and development periods may give up to 75% energy savings. These types of solar-powered systems are tested in countries like Oman [13] where the extreme climate situations may not allow the optimum growth of plants. It is evident that this method is indispensable for countries that seek self-sufficiency in food production. Combined with the benefits that come with energy efficiency using solar power, the application of IoT in automating hydroponics paves way for various applications in daily life. As the maintenance is done automatically, the requirement for advanced skills for applying this system is greatly reduced [14-15]. The main advantage is the reduction of human errors and we do not need to worry about the manual addition of nutrients which is an area where not all will be skilled enough.

The main problem hydroponic systems face despite all the advancements is disease detection. It is prone to water-borne diseases and early detection is necessary. Detection of diseases by image processing [16] using Raspberry Pi is an important technology that is relevant in hydroponics and similar sustainable technologies.

III. METHODOLOGY

This work is an automated hydroponic system that makes use of TDS (Total Dissolved Solids)sensor, pH sensor, temperature sensor, and humidity sensor to check the parameters. The pH and dissolved solids in water are measured in addition to the humidity and temperature using the DHT11 and DS18B20 sensors. The parameters are displayed through an LCD. The system would automatically adjust the parameters with the help of IoT, and the measurements can be viewed via a web application in real time.

The block diagram of the system is given below.

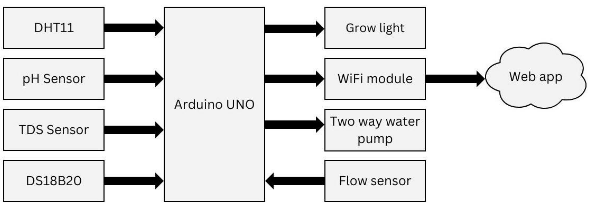

fig. 1: Block diagram

The actuators control the flow and level of water. These sensors are placed in the water for continuous data gathering. The pH sensor, DHT11 sensor, DS18B20 sensor, and TDS sensor are connected to the GPIO pins of the Arduino UNO development board. The LCD display is interfaced through I2C configuration to view the measurements of the system.

The Internet of Things (IoT) plays a significant role in the automation process. The most important component is automating this hydroponic system, which is readily accomplished by linking the hydroponic system with the IoT. The cloud database serves as the central hub for the whole automation process; it holds all of the information about the hydroponic system, including data obtained from the crops and the water tank. Sensors and actuators are utilized to automate the hydroponic system; sensor readings are uploaded to a cloud database, from which the user receives real-time information on the state of the crop. The mobile application contains all of the hydroponic system specifications; the user must have a unique login ID. The user name and password are saved in the cloud database, allowing the user to work on his agricultural field without interruption.

A. *Image processing*

Image processing techniques can be used to identify illnesses in hydroponic plants. Plants are grown in nutrient-rich water solutions rather than soil in hydroponic systems. Because the roots of hydroponic plants are submerged in water, it might be difficult to identify illnesses visually. By analyzing photos of the plants to detect symptoms of illness, image processing may be utilized to solve this problem. Here are the general steps involved in using image processing for disease detection in hydroponic plants:

Steps:

- Through the camera, pictures of the plant's leaf are recorded. Red, Green, and Blue, or RGB, is the format for this image. A color transformation structure for the RGB leaf image is created, and then a device-independent color space transformation for the color transformation structure is applied.

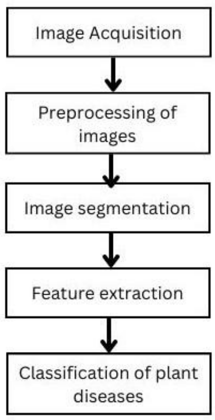

fig. 2: Steps involving image processing for disease detection.

- Various methods are used to remove noise from images and other objects. Techniques for pre-processing are considered. Image clipping i.e. cropping the leaf image to get the interesting image region. The smoothing filter is used to smooth out images. Image Enhancement is used to increase the contrast. Color conversion is used to convert RGB

images to greyscale images. Then the histogram equalization which distributes the intensities of the images is applied to the image to enhance the plant disease images.

- It entails dividing an image into sections with similar or identical features. Otsu’s method, k-means clustering, converting RGB images to HIS models, and other methods can be used for segmentation. The RGB image is converted into the HIS model for segmentation using the Boundary and Spot Detection Algorithm. Boundary detection and spot detection aid in locating the infected part of the leaf. The 8-pixel connectivity is used for boundary detection, and the boundary detection algorithm is used. K-means clustering: K-means clustering is used to classify objects into K different classes based on a set of features. Objects are classified by minimizing the sum of the squares of the distance between the object and the corresponding cluster[17]. The K-means clustering algorithm is as follows:

1. Select the center of the K cluster, either randomly or based on some heuristic.
2. Assign each pixel in the image to the cluster with the shortest distance between it and the cluster center.
3. Determine the cluster centers by averaging all of the cluster's pixels. Continue performing steps 2 and 3 until convergence is reached.

- Otsu Threshold Algorithm: Thresholding converts grayscale images into binary images by assigning the values zero and one to all pixels below a predetermined threshold. The Otsu algorithm is as described:
 i) In light of the threshold, find the average value for each cluster after dividing the pixels into two groups.
 ii) Squaring the mean difference
 iii) Divide the sum of the pixels in each cluster by the sum of the pixels in each cluster. By altering the colors, the illustrated leaf displays the disease's symptoms. The infected area of the leaf can be located using the leaf greenness of the leaves. The components R, G, and B are taken out from component GE.

- Using Otsu's method, the threshold is calculated. The green pixels are hidden, and the threshold cannot be calculated for their pixel intensities.

- Feature extraction plays a significant role in identifying an object. Image processing feature extraction is frequently used. Color, texture, morphology, edges, and other characteristics can all be used to identify plant diseases.

- Utilizing ANN: Following feature extraction, images from the learning database are classified using neural networks. In an ANN, these feature vectors are regarded as neurons. The weighted sum of the inputs determines the neuron's output. The back propagation algorithm, Multiclass Support Vector Machines, and Modified SOM can all be used.

IV. EXPERIMENTAL SETUP

As a part of implementing the system, the seedlings are raised in grow cubes before transferring them into the system.The plants are placed in pipes such that the roots come in contact with the flowing water.

fig. 3: Setup of the Automated Hydroponics system.

The automated hydroponic system is set up as shown in Figure (4). A reservoir is attached to the bottom of the system where a pump facilitates the circulation of water. The required nutrients are added to this reservoir. Various sensors measure the parameters of the water and send these data to the firebase, using which we can view the changing parameters through the mobile application. The data obtained from the Arduino board is displayed through the LCD at the same time.

fig. 4: Nutrient Containers and Reservoir

The crucial part of this system is the maintenance of nutrient levels in the water. There are three main types of nutrients that are added: Sodium, Potassium, and Phosphorous. These nutrients are taken in separate containers outside the container. The individual nutrient values can be derived from the obtained TDS (Total Dissolved Solids) value from the analog sensor. Whenever the level of nutrient varies or specifically, decreases from the required threshold value, the adds required nutrient into the water.

V. RESULTS AND DISCUSSION

The hydroponic system is implemented using sensors and Arduino. There are three types of nutrients: Sodium, Potassium, and Phosphorus. Mini pumps are used to pump nutrients into the water whenever it is required. The system will detect the abnormality in nutrient levels and automatically adjust it. These parameters can be viewed through the mobile application in real-time.

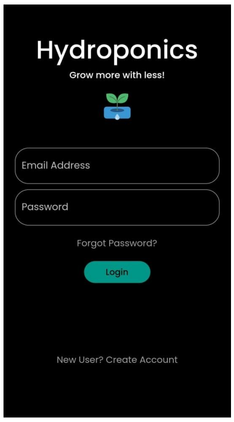

fig. 5: UI of the mobile application

The given figure (5) is the UI of the web application developed for the real-time monitoring of vital parameters of the hydroponic system. Each user needs a unique user ID and password to log in.

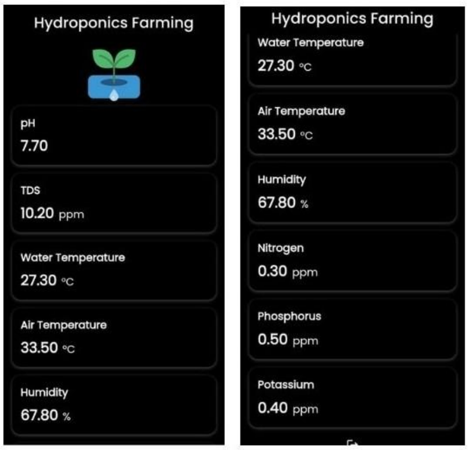

fig. 6: Reference values and obtained values of various parameters.

The web application is set up with Firebase as its database. IoT is used to connect the sensors to the cloud. The data obtained from the sensors are displayed in real-time through the app by making use of IoT. In figure (6), the preliminary results are displayed after setting up the system.

Different kinds of crops can be grown using hydroponics. However, each plant needs different rates of nutrients and atmospheric conditions to ensure growth. The given table shows the quantity of nutrients and ideal atmospheric values required for cultivating Lettuce.

Sl. No.	Vital Parameters		
	Parameter	*Reference values*	*Obtained values*
1	Water temperature	25°C	27.30 °C
2	Atmospheric temperature	32°C	33.50°C
3	Humidity	50-70%	67.80%
4	pH	6-7	7.7
5	TDS	560-800 ppm	778 ppm
6	N quantity	100-150 ppm	135 ppm
7	P quantity	25-60 ppm	56 ppm
8	K quantity	150-200 ppm	165 ppm

table 1: Reference values and obtained values of various parameters

The given table shows the different ideal levels of the essential parameters and the average values obtained from the experimental setup. As our main concern is nutrient levels, we can see that the system maintained the required nutrient levels automatically.

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