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Management of Unified Control and Automated System for Smart Hydroponics

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The formulated concept was to design and develop a system of automating and managing a hydroponics farm to address the problem encountered in traditional farming, which is too manual and labor-intensive. This problem was addressed by introducing an intelligent way of monitoring and controlling essential water parameters in growing lettuce in a Nutrient Film Technique (NFT) hydroponics. The concept was initiated by designing and developing a management system, developing the hardware and firmware components to control and monitor the NFT hydroponics using the "Internet of Things (IoT)", and evaluating the performance and reliability of the developed system. The management system developed was embedded with the IoT for controlling and monitoring specific actuators for driving the DC and AC pumps, the chiller for desired water temperature, dosing, and fertigation pumps to maintain the pH and EC values for optimum plant growth. All these features were made possible using an open-source development board as the hardware and an Android application solely for the purpose, both components of the developed system that can automatically collect the enormous amount of data generated for the management of hydroponic systems, which is hardly achieved by manual testing as practiced. The management system not only provides sufficient data for decision-making but also eases the monitoring and control of essential water parameters that are critical in the growth of plants.
Keywords: Automation, Hydroponics, Internet of Things, Greenhouse, Lettuce, Smart Farming.

1. Introduction

Agriculture and farming are the primary source of food production for the human population [3]. Farming as traditionally practiced, in third-world countries has been too manual and labor-intensive and will continue if innovations are not put forward. To ensure food security and meet the increasing food demand issue, efforts are in place to improve the quality and quantity of agricultural food products by making farming "smart and precise". According to the Food and Agriculture Organization (FOA) of the United Nations, precision agriculture as an industry is estimated to grow to 43.4 billion USD by the end of 2025 [5].

Soilless farming or hydroponics is a technique of growing crops in a nutrient solution using a media. In a Nutrient Film Technique (NFT) system, liquid nutrients solution are pumps and circulated from reservoir tank to the vertically arrange growing bays. The nutrient solution continually flows along the growing bay made small channels pipe where the root systems sit. NFT adopted by hobby gardeners, as well as those planning a commercial venture, because the method of growing plants requires minimal and efficient water usage by using circulating watering system. Propagation cubes of stonewool usually support the seedlings or young plants. Common practice uses coco pit together with small lattice pots slot into the top surface of the growing channels. The circulated nutrients in the growing channels, passing through the root systems are flowed back to the main reservoir for adjustment and monitoring.

The standard target nutrient for growing lettuce best is "150 to 200 ppm N or 1.0 to 2.0 mS/cm for hydroponic nutrient solutions [14]. Excessively high or low salts can significantly affect the quality of greenhouse-grown lettuce. A solution EC of 1.500 mS/cm during production should be maintained. It is important to note that Ca(NO3)2 must be maintained in a separate stock tank from other fertilizers to prevent Ca from precipitating out of the solution. Increasing transpiration by providing adequate air movement will help facilitate Ca movement to the upper leaves". N. Liu et al. (2012) recommend sub-irrigating transplants with clear water to leach excess salts to correct high EC.

Another parameter needs to control in Lettuce transplants grown in soilless substrates have a more comprehensive optimal pH ranging between 5.5 to 6.5. Commonly, hydroponic lettuce shall be produced using a narrower pH range of 5.5 to 6.0, with an optimal target value of 5.8 [14]. In preparation of the substrate, it is usually maintained between the 5.5 and 6.5 pH range. Low pH can cause stunting, chlorosis, and necrotic spotting on the lower foliage. High pH can limit iron (Fe) availability, leading to interveinal chlorosis on the upper leaves [14].

The use of conventional method to monitor and control these required parameters for growing lettuce crops are too laborious and time consuming. This paper presents how the available technologies are utilized to manage a hydroponic farm which allows the farm attendant to monitor and control the process anywhere and anytime with efficiently.

The IoT is a critical and very popular “Technology” nowadays. Lifestyle controllability based on IoT became considerably more straightforward and more accessible, especially in the communicating approaches among intelligent devices [1]. This technology allows accessing and controlling devices anywhere and anytime.

The Arduino is an open-source electronics platform both hardware and software [19]. “This platform is a nice and easy-way to implement proof of concept. In this project, the researchers utilized Mega WIFI R3 ATmega2560 with ESP8266 USB-TTL. It is an Arduino-compatible customized version of the classic ARDUINO MEGA R3 board. Full integration of Atmel ATmega2560 microcontroller and ESP8266 Wi-Fi R3 IC, with 32 Mb (megabits) of flash memory and CH340G USB-TTL converter on a single board”. [15]. The ESP8266 WIFI embedded adapter contains its TCP/IP stack and CPU operating at 80mhz.

The Android application is convenient way to monitor and control remote sensing and monitoring yet easy to use mobile Application. Using the “MIT App Inventor, which is considered to be an intuitive, visual programming environment allowing to build a fully functional application for Android and iOS smartphones and tablets. The blocks-based tool facilitates complex, high-impact apps in significantly less time than traditional programming environments. Likewise, the MIT App Inventor project democratizes software development by empowering everyone, especially the young ones, to shift from technology consumption to technology creation” [23]. The Android application developed is for managing a hydroponics system working with the IoT platform.

With the application of this evolving and availability of this technology, the project proponents successfully develop and implemented a system for management to control and monitor the primary parameters of water in a hydroponics system that are critical in the production of lettuce a highly valued agricultural crop.

2. Methods and Materials

The project is designed to automate the fertigation requirement of an NFT hydroponics system through a unified control and monitoring system for various essential water parameters with the IoT. The use of sensors and microcontrollers and the internet plays a vital role and that make sense in this project. Using the developed system, the farm manager/owner can remotely monitor the conditions of the essential parameters in the hydroponics greenhouse even without going to the area. Figure 1 shows the conceptual framework of the study.

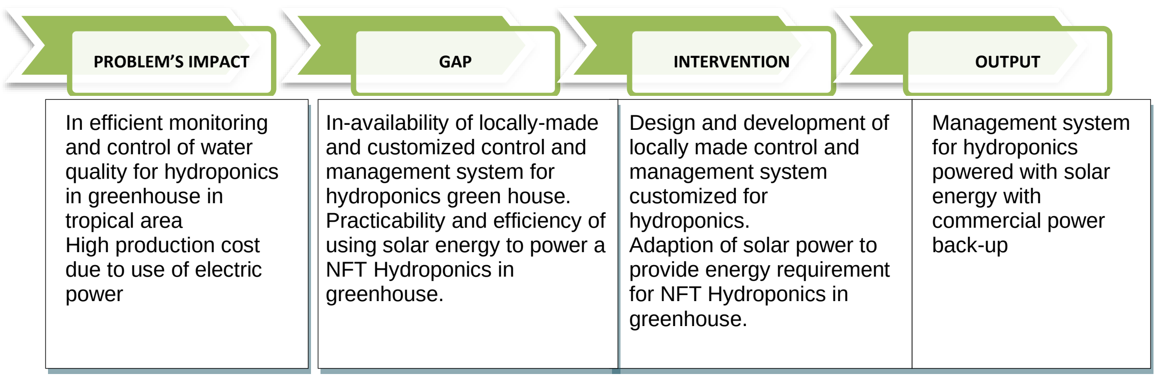

Figure1. Conceptual Framework of the Project

The project implementation has undergone four phases:

Phase 1: Design consideration

Phase 1 is focused on the design of the system based on the requirement of the plants to be grown (lettuce in this case). Design consideration includes the arrangement of pumps and tanks for efficient use of electric energy to power the pumps, temperature consideration, and the variables to be controlled and monitored, such as EC, pH, size of pumps, placement, and arrangement of tanks and chillers. Figure 2 illustrates the system's operational diagram.

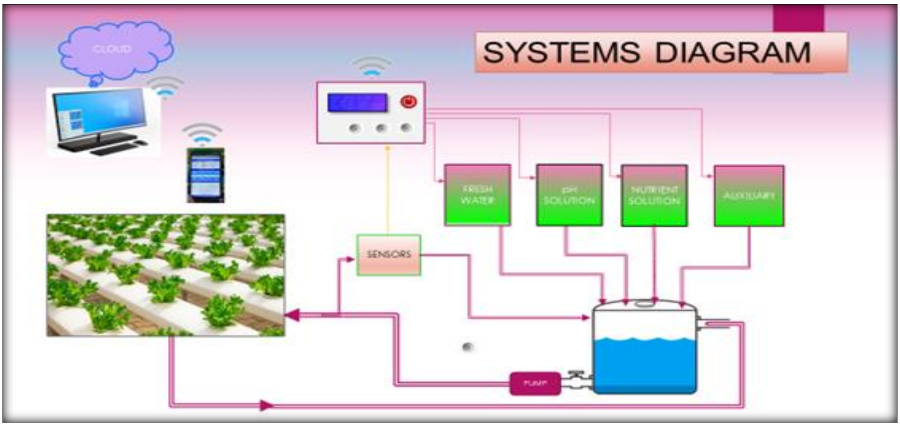

Figure 2. Operational Systems Diagram

Phase 2: Development process

Phase 2 is mainly on the development process of the control and monitoring system using the open-source development board. There are at least three major components the system has: (1) a control and monitoring management system having sensors and actuators; (2) an interface for the IoT; and (3) the mobile device application software.

2.1. Connection to the internet using SSID and password

The connection depends on the availability of the network and which network to connect to. The firmware developed can identify and select the available network to secure. In this project, we provide dedicated WIFI connectivity on-site using the public network provider. We also provided a backup WIFI connection using a repeater to which the system will connect whenever the other network fails. The system will proceed to program events when everything is under normal conditions, meaning there is an internet connection. The system will move to the subsequent program events if no internet connection is available. The system will still work even without an internet connection to manage the water nutrients of the NFT system.

2.2. Reading of temperature.

The system utilizes the DS18B20 single intelligent temperature sensor manufactured by DALLAS semiconductor companies in the United States in reading temperature values. This “new generation of adaptive intelligent temperature sensors can directly convert temperature signals to serial digital signals for computer processing” [20].

This DS18B20 is submerged in NFT circulating nutrients to detect the water temperature. Suppose the temperature rises beyond the set value. In that case, the system will turn the chiller ON to lower the temperature. Aside from this auto control of the chiller, the switching can also be done using the override switch. Override switching can be performed either by manual switching controlled locally or can also be performed online using the advanced android application.

2.3. Reading of pH

In reading the water pH, an analog pH sensor kit from DIY MORE. This pH sensor kit is designed to measure the pH values of nutrient solution circulating in the NFT system. The technique developed within the system is made such that the it won't interfere with the measurement of EC. This can be done by creating a reasonable precision provided through an excellent sketch. The "board contains a pair of trimmers to adjust the analog reading offset" [21]. It has indicating LEDs for power indicator, a pH sensor reading.

Using either type of pH sensor, the program in the developed system can quickly adapt to whichever kind of sensor is preferred. A sensor calibration test using at least two different pH solutions is essential. After calibration, the system can now determine the value of pH in the hydroponics nutrient solution.

With the use of the pH sensor, auto-dosing is also performed to maintain the pH level of 5.8 in the nutrient solution. Auto dosing is programmed every 15 minutes when pH is out of range. This allowed the nutrients to circulate in the NFT system before another dosing occurred. Auto dosing runs for around 30 seconds to provide a 10ml balancing solution either to increase or decrease the pH level. In this setup, dosing could change the pH level by around +- 0.1 for every dose cycle.

2.4. Reading of Electrical Conductivity (EC)

The parameter to measure EC is made using the sensor made of two metal plates to measure the electrical conductivity in between the metal plates, which is related to the ability of the material to carry the current. In the developed system, the electrical flow between these metal plates is measured and used as a reference to measure the amount of resistance. The reciprocal of the resistance measures its ability to conduct electricity. The nutrients' electrical conductivity is determined by the salt dissolving in the nutrient solution circulating in the NFT system and is processed electronically. The results reflect the extent of electrolytes present in water.

2.5. Reading of water flow rate

The water flow rate sensor consists of a plastic valve body, a water rotor, and a hall-effect sensor [22]. When the water flows through the rotor, the rotor rolls, and its speed changes with the different flow rates. The hall-effect sensor yields the corresponding pulse signal. The proponent uses a sensor with a flow rate of 5 to 120 liters per minute (L/m) ranges in this project. The sensor has about 38mm in diameter. The readings from this sensor are monitored through an LCD found in the central controller and sent over the internet for monitoring. Parameters can be monitored using a computer and/or the developed android application.

2.6. Reading of humidity

The humidity within the greenhouse is determined using the BME280 module sensor. When interfaced with Arduino and provided with appropriate sketches, this sensor module can read the greenhouse's barometric pressure, temperature, and humidity. The proponents use the I2C communication protocol in the developed system to exchange data with a microcontroller. The humidity sensor is placed inside the greenhouse and has its microcontroller. A wireless sensor sends data to the cloud like the central controller. All the data from wireless sensors are sent over the internet using ThingSpeak. They can be viewed on the developed Android application and are available for monitoring.

Phase 3: Testing and Revision process

Phase 3 involves the installation, implementation, testing, revision, and calibration of the developed controller system for managing hydroponics in lettuce cultivation. This phase focuses on ensuring the system operates effectively by rigorously testing it under real-world conditions, revising components as needed, and fine-tuning the calibration based on the pre-established nutrient management parameters to optimize the growth and health of the lettuce plants.

Phase 4: Data gathering and interpretation

Phase 4 is the data gathering and interpretation. In this phase, we allow the system to run and manage the nutrient in the hydroponics system with the crops in the growing bay; we monitor and the readings of parameters using the developed system and verified with manual monitoring instruments. Through this test, we established the performance and reliability of the developed system.

3. Results

The developed system manages and interprets signals from multiple sensors in the NFT hydroponics system's circulating nutrient solution. The central processor acts as a client, receiving data from wireless remote sensors and servers, and communicating this data to the cloud. It can read and interpret parameters from local sensors directly connected as peripherals. The system sends data to the cloud for monitoring and receives data for automation. Actuators are automatically initiated when variables exceed set ranges. Primary parameters such as temperature, pH, EC, water flow, and humidity are monitored via a display assembly and an advanced Android application. An override processor assembly allows manual override commands and status override orders from the Android application. Data is logged and monitored over the internet, enabling operators to override the auto-fertigation system remotely.

The developed hydroponics management system was evaluated on its ability to automatically maintain a pH of 5.8 and an EC of 1200-1800 µS/cm in an NFT system for growing lettuce. Pilot testing on actual farms assessed the system's reliability. Issues encountered included data command transmission, sensor accuracy under real-world conditions, and simultaneous sensor operation. Program modifications were made until the system functioned correctly. Sensor accuracy, particularly for pH and EC, was challenging but resolved by isolating sensors and using standard calibration solutions (pH 4, pH 6.8, 12.88 mS/cm, 1413 µS/cm). The system's performance over a month was documented, with daily results shown in Table 1.

Table 1. Sample of Data collected within a Month and sent through the cloud.

CREATED_AT	ENTRY_ID	TEMPERATURE	pH	EC	WATER FLOW
2021-08-17 08:53:51 +08	1	24.44	6.22	1410.35	0.00
2021-08-19 12:06:04 +08	3000	25.00	5.91	1258.63	101.14
2021-08-20 19:51:36 +08	5001	25.00	5.80	1253.97	105.43
2021-08-22 03:52:44 +08	7000	25.00	6.36	1222.63	108.00
2021-08-23 12:18:02 +08	9000	29.19	6.10	1153.58	96.86
2021-08-25 00:30:43 +08	11000	25.00	6.14	1206.67	106.29
2021-08-26 12:34:00 +08	13000	28.00	5.97	1179.74	97.71
2021-08-27 06:46:54 +08	14000	23.13	5.96	1186.83	99.43
2021-08-28 01:48:48 +08	15000	23.75	5.83	1221.69	107.14
2021-08-28 19:38:35 +08	16000	25.81	5.78	1227.23	104.57
2021-08-29 13:49:51 +08	17000	27.81	5.71	1204.96	100.29
2021-08-30 07:11:38 +08	18000	24.81	5.94	1104.07	102.00
2021-08-31 00:32:24 +08	19000	24.69	5.82	1166.58	107.14
2021-08-31 17:39:01 +08	20000	25.56	5.62	1107.41	102.00
2021-09-01 11:51:48 +08	21000	27.50	5.92	976.68	98.57
2021-09-02 06:06:27 +08	22000	22.94	5.83	1148.82	105.43
2021-09-02 23:26:58 +08	23000	24.19	5.88	1069.45	100.29
2021-09-03 17:08:34 +08	24000	26.06	5.77	1334.01	105.43
2021-09-04 11:21:42 +08	25000	27.69	5.66	1226.83	101.14
2021-09-05 05:30:36 +08	26000	23.50	5.93	1279.58	107.14
2021-09-05 23:35:12 +08	27000	24.69	5.65	1232.65	105.43
2021-09-06 17:51:00 +08	28000	26.31	5.67	1366.80	101.14
2021-09-07 11:58:02 +08	29000	25.88	5.65	1112.57	108.86
2021-09-08 05:28:50 +08	30000	24.69	5.57	1186.22	110.57
2021-09-08 22:43:55 +08	31000	25.00	5.80	1001.03	108.00
2021-09-09 15:53:52 +08	32000	26.00	5.75	1095.61	78.00
2021-09-10 09:47:15 +08	33000	24.75	5.94	1087.53	98.57
2021-09-11 03:34:10 +08	34000	23.25	6.00	1411.25	91.71
2021-09-18 05:20:37 +08	36000	25.00	5.69	1437.31	104.57

The data presented in Table 1 shows the values of primary parameters for growing lettuce using the NFT system in tabular form. The system using the open-source platform can also be viewed using a computer device. The monitoring data derived are shown in Figure 3. The parameter such as temperature, pH, electrical conductivity (EC), and water flow are monitored to see if any variation is viewed. Any changes seen are good indications that the sensors are alive. Variations in readings are indications that the sensors are working as expected. Any values beyond desired can be corrected by the system.

The data from the developed system is sent to the cloud can also be viewed when the users log into the account provided using the ThingSpeak™. The proponent uses an paid account to remotely monitor and control the greenhouse using the developed management system. Aside from using the paid platform the system is also provided with the developed mobile application wherein the same data can be viewed remotely. The mobile application is also capable of controlling a particular parameter by switching ON or OFF certain actuator on site.

Figure 3 shows a screenshot of how data are viewed using a computer or mobile devices.

Figure 3. Screen-shot of Data Monitored in a computer.

It was observed that the pH probe gave accurate results for continuous operation for a month. Using the intended calibration solution, the same test was performed with the EC sensor. The EC probe also gave accurate results for continuous operation for a month. However, regarding the life span of the probes used, we could not estimate or verify the manufacturer's specifications due to time constraints in implementing the project.

3.7. The Android App

The developed application is control and monitoring that displays the values of identified parameters monitored from the greenhouse. These values came from the sensors, which were sent to the cloud using an IoT technology. Each channel could receive or send eight (8) fields per channel, making the system capable of receiving data and sending commands from the user to talk to the remote system.

In the developed management system, parameters such as temperature, pH level, EC level, humidity, and water flow are simultaneously monitored. It also monitors the state of actuators, including the chiller, dosing, DC, and AC pumps, including the mode status, which can be selected between normal and night mode. In the normal mode, the user can choose to use the DC or AC pumping of circulating water in the NFT system.

Figure 4 shows the screenshot of the developed Android application software installed on an Android mobile device.

Figure 4. Screenshot of the developed android application software installed in the android mobile device showing the control panel (left) and the display panel (right).

The display panel on the right consists of button switches wherein the user can remotely intervene in the system. These buttons include the switching between AC pumps and DC pumps for NFT circulating water supply, the dosing, the control of turning ON and OFF of the chiller, which can also be programmed for the desired time, and the Normal and Night modes. A command status is also displayed when any of the buttons is activated, allowing the user to know if the command is successfully sent. The user can also switch screens to view either the control panel or the display panel.

4. Conclusion

In conclusion, the developed hydroponics control system efficiently manages and interprets signals from sensors in the NFT hydroponics system. The central processor, a key component, receives data from wireless remote sensors and servers, and effectively communicates the data to the cloud. The system can read and interpret parameters from local sensors and automatically initiate actuators when variable parameters are beyond ranges. The system monitors primary parameters such as temperature, pH, EC, water flow, and humidity using a display assembly set that displays the parameters' status.

The developed Android application receives sensor readings and displays values of essential parameters from a remote location. The Android application can also be initiated by the user to generate override commands using manual buttons. The operator can override the system operation in the field over the internet. Yet the system maintains an auto-fertigation system that works without an internet connection. The temperature sensor utilized the DS18B20 single intelligent temperature sensor, while the pH sensor kit from DIY MORE was used to read water pH. The Gravity Analog Electrical Conductivity Sensor from DFRobot was utilized to monitor EC, and the water flow sensor connected to the Arduino and provided with sketches to make the systems functional. The developed system allows for a more precise and automated approach to hydroponic nutrient management. Importantly, the applicability of the developed system was tested in actual use, and production increased by an impressive 160 % compared to the traditional farming method used by the partner industry, demonstrating its effectiveness.

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