Automated hydroponic nutrient control system for smart agriculture

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ABSTRACT

Hydroponics is a type of soil-free farming that uses less water and other resources than conventional soil-based farming methods. Hydroponic cultivation system has high yield per acre of land with minimal consumption of water and can be a possible to meet the growing food demand of the world. The hydroponic plants fertility must be preserved, proper nutrition, a environmental temperature, and nutrient stability are crucial. It will be simpler for a farmer to keep track of all hydroponic plants by automatically monitoring nutrient flow and ambient temperature stability. By implementing artificial intelligence-based regulating algorithms in the agriculture industry, recent technology advancements are highly helpful in resolving these issues. This paper presents, automated hydroponic nutrient control system (AHNCS) for smart agriculture. System architecture is consisting of sensors network, Raspberry pi 4 microcontroller and actuators. Raspberry pi 4 microcomputer read sensor values from sensors process and activates particular actuator. The automation of the hydroponic system helps to avoid human intervention. The utilization of sensors and actuators, promptly act for the needs of the plant without any delay. The AHNCS having high accuracy, high efficiency and less delay. Hence, automation of the existing hydroponic system can reduce human dependency, provide accurate results, constant monitoring of plant health.

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1. INTRODUCTION

The population of worldwide has grown 1,860 times throughout the last twelve millennia. In highly populated urban areas, the population grows dramatically. The productivity of traditional farming confronts multiple challenges. The world's population is growing, which results in less open area being available for plant growth and maintaining the food supply for everyone. Global climate change, pollution, the loss of crop-growing soil integrity, a rapid increase in urbanization, agricultural land sacristy, and other issues are some of the concerns in rural regions [1]. Therefore, farmers must practice smart farming, which might help in increasing food production yields [2]. In order to address the global food issue, both these new farming techniques and old agricultural techniques need some technology support. Utilizing advanced agricultural techniques like hydroponics, vertical forms, and polyhouses is important to overcome these problems [3]. The finest growing technique among them that directly addresses technology needs is hydroponics [4].

Hydroponics is a soilless agriculture method which grows plants using nutrient solutions, consisting of required minerals in water [5]. The plant factories employ hydroponic systems for growing leafy vegetables and other vegetables because of their inherent advantages such as automated irrigation, Low cost of labour, isolated environment, cultivation in layers [6]. Smart agriculture is one of the new types of information and fine management modes. The main aim of this smart agriculture is to provide the intelligent control of circulation and production of agriculture [7]. In order to maintain the fertility of hydroponic plants, proper nutrition and temperatures in the environment stability of nutrients are important.

The standard of hydroponic plants is often maintained manually by maintaining monitoring on the water's temperature, electrical conductivity, total dissolved solids (TDS), pH, and acidity or basicity (pH) values [8]. The farmer needs a tool that can communicate automatically in order to monitor and manage the temperature height of the nutrients in the hydroponics environment [9]. Increased plant growth based on the preserving nutritional value (such as pH, TDS, and electrical conductivity (EC)) and two advantages of using internet of things (IoT) include a decrease in plant maintenance costs of between 23% and 70%. The agriculture 4.0 is a data-driven model which uses modern technologies for monitoring the traits, life cycles of plants and results better yields [10]. The idea of the IoT allows for real-time remote monitoring and control through internet media.

The hydroponics or hydroponic system is the solution that can satisfy these needs and this method is already employed in the horticulture [11]. Hydroponics is a plant production technique that does not use soil and, make use of water and nutrient solutions only to grow plants. Deep flow technique and nutrient film technique are commercially used hydroponic systems to grow leafy vegetables [12]. In general land agriculture, irrigation and fertilization of plants need so many efforts in terms of labours and money. Most plant factories make use of hydroponics because of their added advantage of automated control of fertilization and irrigation which also saves labor. Indoor or greenhouse growing conditions keep the environment clean and control pests and their diseases [13]. Therefore, automated hydroponic nutrient control system for smart agriculture is represented in this paper.

Recently, industrial robots and artificial intelligence (AI-based) autonomous robots with a range of hardware controllers have become crucial in hydroponics for plant monitoring [14]. The booming IoT is becoming area of interest for researchers and industrialists. Increased plant yield and reduced maintenance cost can be observed in hydroponics utilizing the IoT [15]. There has been substantial work being carried on the application of IoT in hydroponics for sensing, wireless communication and remote monitoring [16]. Arduino microcontroller-based monitoring system was developed to gather data using sensors such as pH sensor, electrical conductivity sensor. Wireless communications are established using sensors network using Xbee and GBoards to control the parameters of hydroponic system [17]. Water flow control in hydroponics is implemented through use of water flow sensor and servo motors to adjust the required flow. IoT is employed to monitor such a system. Web interface were developed for accessing, monitoring and controlling through cloud [18]. Remaining paper is organized as follows: section 1 presents introduction, section 2 expands on the literature review, section 3 represents the described automated hydroponic nutrient control system (AHNCS), experimental results are represented in section 4 and the conclusion of the paper is represented in section 5.

2. LITERATURE SURVEY

An advanced fuzzy logic based framework is described to control the switching time of pumps through the user defined variables. One of the most important contributors of the system is sensors. This system provides better performance and acts as an interface between input and sensors. The IoT acts as output medium. The performance of this system is compared with manual handling systems. The results indicated that watering time and consumption of water was reduced [19].

A pest prediction approach is described to prevent pest. The IoT infrastructure collects the data. The data is analyzed to know the breeding conditions of pests. This approach verified that, weather factors have more impact on pest and disease occurrences and this system provides development services through IoT and it is helpful for the farmers to take the precautionary measures [20].

The main aim is to design a multisensor machine-learning approach (MMLA) to classify multiple sensor information. Fusion analysis supports higher quality data analysis to recommend the cultivations in agriculture fields. This recommendation system classified different crop types such as wheat, sugarcane, and moong. the usage of multiple sensors with data fusion has shown better yields in different environmental conditions [21].

A multimodal communication system is described to ingrate multiple vendors in a systematic way in agricultural productions. Data distribution service (DDS) middleware model is used for enabling the communication between production systems to do farming actions in a sequential way. Experiments are performed over a small scale farm for evaluating the performance of system in terms of packet delivery ratio (PDR), throughput and latency. From the results, it is observed that this system enabled the interoperability's between multiple vendor productions in real time and have very less latency [22].

Using combination of sensors to identify the outcomes of data fusion, this system requires minimizing information sharing of multisensor data fusion inside the wireless sensor network. It has automated controls for water level, humidity, and temperature as grower settings. Additionally, it transmits sensor data and status, gathers pH and EC readings from every nutrient solution tank, and uses an Android mobile application to provide notifications. The analyzed findings demonstrate that the system is capable of making an accurate setting decision based on the outcomes of multisensor grouping [23].

This approach performs various experiments with multiple clustering based segmentation approaches and the features like local binary pattern (LBP), gray level run length matrix (GLRLM), segmentation-based fractal texture analysis (SFTA) and gray level co-occurrence matrix (GLCM). This approach provided automated decision supports to classify different types of plant leaf diseases using cloud server which is accessed through an app. This system shows good results in humid and hot weather conditions and is reliable for diseases identification like certain types of vegetables, vegetable farmlands and crops water regulation [24]. Initial framework architecture is described. This framework is designed for developing various applications based on the obtained insights and experiences. This framework is revised in iterative procedure. This architecture is demonstrated in different uses cases and every use case indicates different requirements of data integration based on the provided services [25].

Megantoro *et al.* [26] discusses the design of a hydroponic planting process monitoring system based on the IoT. This device uses an ESP32 microcontroller board as the main controller. The parameters that were monitored and acquired were the conditions of the hydroponic growing media. Those parameters are; water pH, water temperature, water turbidity level, and ambient air temperature and humidity. The five parameters are measured by analog sensors integrated with the ESP32. These parameters affect the growth process and the quality of crop yields. Thus the results of monitoring can be used to optimize the process of growing hydroponic plants.

3. AUTOMATED HYDROPONIC NUTRIENT CONTROL SYSTEM

The system architecture of the automated hydroponic nutrient control system for smart agriculture is represented in Figure 1 numerous sensors, actuators, and controls make up an automated hydroponic system. Data on the characteristics of a hydroponic system, nutrient threshold values, the availability of electrical systems, and actuator availability are first gathered in order to design an automated system. Design of system architecture is done with use of sensors, actuators and controllers. The sensors that are utilized are LM35 (linear model) temperature sensors, pH sensors, humidity sensors, and water level sensors. Raspberry Pi is used to analyze the gathered sensor data, process it and control the actuators. If Temperature of the environment is too high which is detected by the temperature sensor, then cooling fan will be on in order to maintain the minimum temperature. If humidity is low then buzzer will be blown. Here temperature and humidity sensing parameters are working on mutual coordination. pH sensor is useful for measuring the acidity or alkalinity of water. Water level sensor handles on and off conditions of the water motor. The values of these four parameters are presented on the liquid crystal display (LCD) module.

Relays are used in this system to control devices like the water motor and cooling fan based on temperature and water level (high/low). Relays are used as a switch to turn on and off the devices that receive Raspberry signals. Based on continuous sensor data and status checks for plant diseases, an automated hydroponic system will inform farmers as necessary. Lastly, the nutrients that are supplied to the plants are up to the levels which are defined by farmer because he has complete control over his hydroponic farm. The nutrients are also given to the plants at specific reference levels while operating in an automated mode.

The Raspberry Pi is a line of small single-board computers (SBCs) that were developed by the Raspberry Pi foundation and broadcom in the United Kingdom. For applications like robotics, the initial model's performance more than expectations when it was marketed outside of its target markets. It is commonly used in a number of sectors, including climate monitoring, because of it is low cost, modularity, and open architecture. It is frequently used by computer and electrical consumers since it complies with the universal serial bus (USB) and high-definition multimedia interface (HDMI) standards.

A pH sensor can be used to determine whether water is acidic or alkaline at pH levels between 0 and 14. The pH of water begins to decrease when it drops below 7. More alkaline values are found above 7. Different pH sensors operate in different ways to measure the quality of the water. The pH of the solution is determined by submerging the pH sensor's electrode in the test solution and holding the probe there long enough for the hydrogen ions to coexist with those on the glass electrode's surface. pH measurement is stable as a result of this equilibrium. The water level sensor module includes numerous parallel illuminated tracks for monitoring the number of droplets/water in order to determine the level of water. Water level can be easily monitored since the analogue signal's output is exactly proportional to the level of the water. These output analogue values can be read straight through the analog to digital converter (ADC) and also connected straight to the analogue input pins on the Raspberry Pi.

By detecting and measuring temperature, temperature sensors are devices that transform temperature information into an electrical signal. The analog output voltage of the LM35 temperature measuring device is proportional to the temperature. The voltage that it outputs is expressed in Celsius. A humidity sensor detects, measures, and records the relative humidity (RH) of the air as the amount of water in a gas mixture (air) or a pure gas. Humidity sensing is linked to the water adsorption and desorption process. Products that are used in agriculture and industry are monitored by using humidity sensors. The digital temperature and humidity sensor (DHT11) is an inexpensive, easy to use digital temperature and humidity sensor. It doesn’t require analogue input pins since it uses a thermistor and a capacitance humidity sensor to monitor the air's humidity and creates a digital signal on the data pin. Although it is easy to use, precise timing is needed when gathering data from sensors.

The algorithm of described automated hydroponic nutrient control system for smart agriculture is represented in Figure 2. Whenever power is supplied to Raspberry Pi micro computer, then it is used to analyze the gathered sensor data, process it and control the actuators. If Temperature of the environment is too high which is detected by the temperature sensor, then cooling fan will be on in order to maintain the minimum temperature. PH sensor is useful for measuring the acidity or alkalinity of water. If it’s value is greater than reference than light-emitting diode (LED) light glow. If humidity is greater than threshold then buzzer will be blown. Water level sensor handles on and off conditions of the water motor. Like this system is operated in an efficient way.

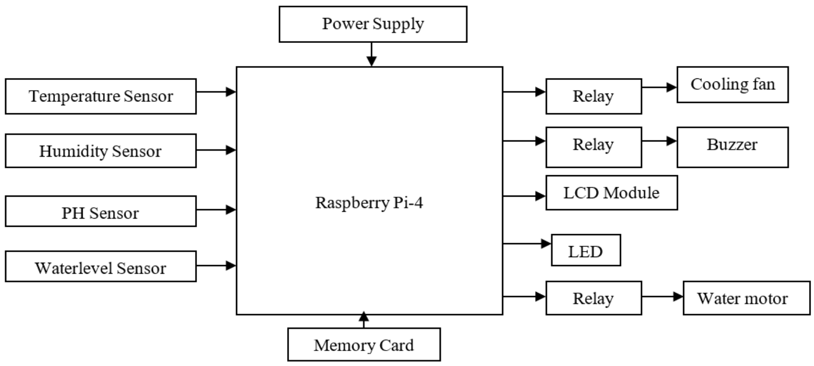

Figure 1. System architecture

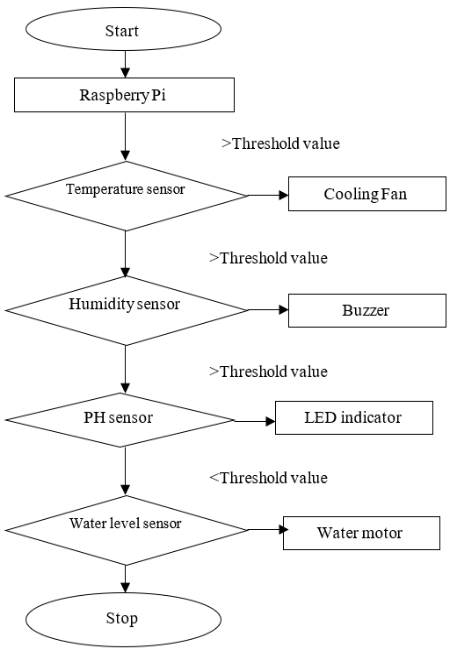

Figure 2. Algorithm for described system

4. RESULT ANALYSIS

The sensors in the system are initiated by providing the power supply. The sensor values are displayed on the LCD display screen of the system. The sensors and actuators work according to the desired conditions and their respective values are displayed on the LCD display. The primary principle of hydroponics is to utilize water for providing the plant with nutrients. The salts are dissolved in the water. The water is continuously rotated in and out of the tank to ensure the water does not become stagnant and saturated.

Raspberry continuously monitor the sensor data and displays this data on LCD module. The threshold value of the temperature is set at 35 °C. Generally, the threshold for the temperature is set around 25-35 degrees. This threshold is decided based on the nature and requirement of the plant. Therefore, as the temperature of the system increases beyond 35 °C, the fan is switched ON. The threshold value of water level in the water tank is set to 300. Therefore, the motor pump acts consequently when the water level decreases or increases.

Through a hydroponic plant completely absorb the nutrients from the water, the water has to maintain a certain pH value. It can be around 6 to 8 and can vary among different plants. Hence, a pH sensor is utilized to continuously measure the pH value. All these values are displayed on an LCD display. This helps the owner to quickly check on the status and health of the plant without spending any physical examination effort. The automation of the system also makes sure that there is a continuous supply of water to the plants even in the absence of the owner for weeks.

The automated hydroponic system is setup along with 2 water tanks. The plant roots are dipped in the water. The 2 water tanks involved in this system namely-primary and secondary tanks provide water to the plant. The primary tank contains the water level sensor. If the water level drops below the predefined level, the motor pumps water from the secondary tank to the primary tank.

The humidity in the hydroponic environment changes as a result of transpiration and changes in the external environment. It is important to maintain the humidity of the hydroponic environment with a cooling fan and Buzzer. According to Figure 3, the relative humidity within the hydroponic environment ranges from 67% to 74%. For growing hydroponically, the upper and lower threshold limitations for humidity are 50% and 80%, respectively. The minimum and maximum values are both inside the threshold limitations. To ensure that the plants grow properly, it is essential to maintain the pH at the prescribed level. The pH value change over a specified time period is shown in Figure 4.

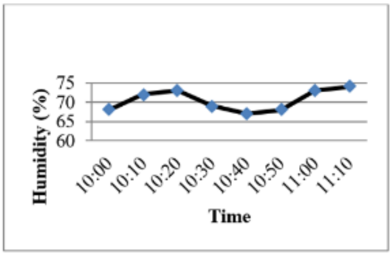

Figure 3. Sensor data of humidity with time

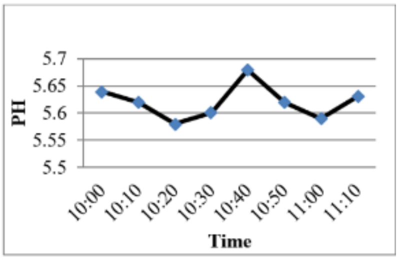

Figure 4. Sensor data of PH with time

As can be seen, during the hours of 10 a.m. and 11 a.m., the pH value measured in the hydroponic environment ranges from a minimum value of 5.58 to a maximum value of 5.68. Transpiration and changes in the external environment impact the hydroponic environment's temperature. A cooling fan is used to maintain the temperature of the hydroponic environment.

According to Figure 5, the temperature value recorded in the hydroponic environment varies throughout a specific time period from 23 °C at the lowest to 34 °C at the highest. The highest and lower threshold limits for a hydroponic climate are 230 °C and 350 °C, respectively. The minimum and maximum values are maintained within the threshold limitations. Therefore, as the temperature of the system increases beyond 35 °C, the fan is switched ON.

The performance of this automated hydroponic nutrient control system is analyzed by using comparative analysis which includes conventional hydroponic nutrient control system (CHNCS) and this AHNCS. Accuracy, delay and efficiency are performance parameters used in this paper. Information or measures are said to be accurate if they are true or correct, to the smallest detail. Graphical representation of Accuracy is as shown in Figure 6.

Efficiency is the quality to do a task successfully while wasting zero time or energy. The graphical representation of Efficiency is illustrated in Figure 7. Similarly, Figure 8 represents graphical representation of delay of two systems. The AHNCS having high accuracy, high efficiency and less delay compared with CHNCS.

Therefore, the system can autonomously run and remotely monitor a hydroponic system. This strategy not only differs from traditional farming practices and enhances the entire process, however, it additionally supports sufficient self-sufficiency to produce everything required throughout the growing season. This analysis demonstrates the properly monitored and managed hydroponic systems exhibit faster rates of development while also reducing reliance on human labor.

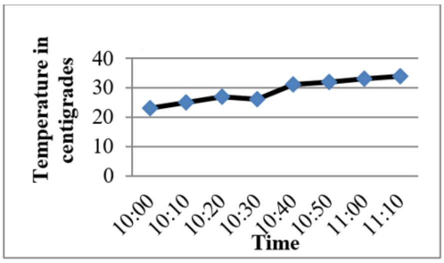

Figure 5. Sensor data of temperature with time

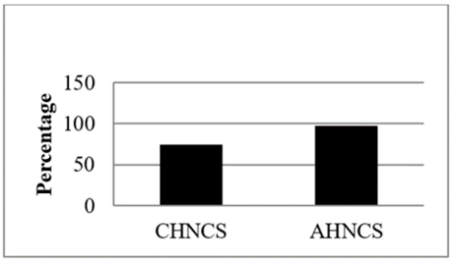

Figure 6. Accuracy analysis

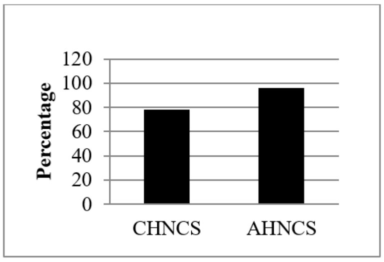

Figure 7. Efficiency analysis

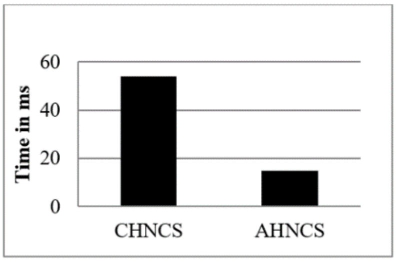

Figure 8. Delay analysis

5. CONCLUSION

In this analysis, architecture of the automated hydroponic nutrient control system for smart agriculture is represented. A Raspberry Pi controller-based hardware solution is created to monitor plant statics utilizing a number of sensors in a hydroponics farm field. Additionally, the information from these sensors is transmitted to a microcomputer and then to actuators. The sensors that are utilized are LM35 temperature sensors, pH sensors, humidity sensors, and water level sensors. To turn on and off the devices that receive Raspberry signal, relays are used as a switch. The presence of each module is carefully arranged to contribute to the best functionality of the unit. Threshold values of the sensors are considered based on the desired conditions of a plant. The AHNCS having high accuracy, high efficiency and less delay compared with CHNCS. Hence, automation of the existing hydroponic system can reduce manual errors, provide accurate results, constant monitoring of plant health.

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