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Automated IoT-Based Monitoring and Control for Hydroponic System

Vaira Muthu K [1], Dr. Krishnakumar A [2]

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Abstract: Agriculture, the world of farming is an essential area where the people around are focusing to develop to enhance more yields in minimum cost and other requirements. The new emerging technique named hydroponics focuses in developing a greenhouse that involves developing crops using water-based nutrients without soil. This proposed implementation presents an intelligent design that comprised with low-cost and automatic monitoring control through the support of IoT (Internet of Things) for hydroponics greenhouse. This implementation includes some sensors to monitor and controls pumping of water, a quality of water, monitor the temperature and humidity of the crops. The master node controls the water flow and aggregates the data, which is received from the member nodes. Member nodes monitor the temperature and humidity and forwards the data to the master node for necessary actions. A Fuzzy inference model is proposed to determine the flow of water and nutrients. The proposed model outperforms than the existing model in low cost, better energy efficiency and throughput.

Keywords: *IoT, Hydroponic System, WSN, Fuzzy Inference Model, Energy-efficient.*

1. Introduction

Agriculture is a backbone of any country. In India, agriculture contributes 19 percent of Gross Domestic Product (GDP) in 45 percent of geographical area. As a drastic growth of population, the agricultural lands are converted into industrial areas and thus makes a shortage of food and food products requirements in all developing countries. As India's population is expected to reach 142.86 crores in 2025 in [1], with the increasing population, demand of food also increased, but the agricultural area is decreasing. Between the years of 2000-2023, the land requirement was demand to increase to 48 percent and actually,it's reduced to 42 percent.

The report in [1,2] estimates that the water scarcity in India may increase rapidly in 2050. The projected food requirement may reach to 481 to 525 million tons by 2060 to 2075. Thus, the Indian economy depends on agriculture and it makes new practices and technological inventions to improve the growth of agriculture in the minimum land. Further, clean water for cultivation is also reducing.The groundwater crisis is an important factor and Punjab in India is facing this crisis and mightdrought in 25 years [2]. As smart agriculture must provide enhanced security to agriculture farms as there may a threat to agriculture lands in the future. Smart agriculture also must enhance production, monitoring and controlling of plants from disease identification, intruder detection and so on.

The Internet of Things (IoT) supports to control and monitor the agricultural farm through its energy-efficient techniques[3]. Generally, the IoTcomprises of controllers, sensors and actuators to provide information about the growth of a plant and reduce the utilization of resources through suitable actuators.As the smart agriculture may provide a better production, yet the utilising of finite resources such as water, nutrients, land. Through adopting smart agriculture techniques the less utilising of resources is in need to improve increase to yield with less water and land requirement. Vertical farming is a technology provides a way to deal with shortage of land and water. Vertical farming is an eye-opening technique, where to do agriculture in rooftops and high-story buildings. Figure 1 shows traditional hydroponic architecture.

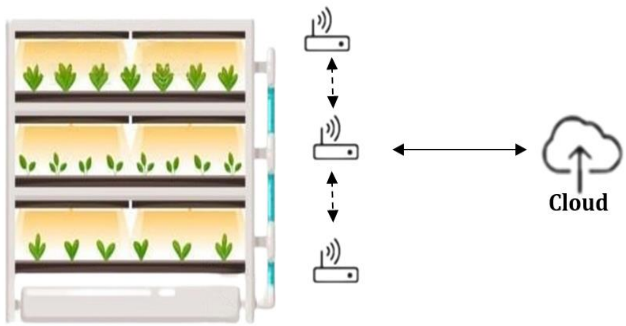

Fig 1. Traditional Hydroponic Architecture

This farmingrecommends the farmers about weather-based recommendations to improve crop yields and develops a smooth cultivation to improve the quality in farming with minimal soil methods. This paper deals with selection of a fuzzy based inference system to improve the crop yield in hydroponic system with less cost and resources.

This section coversIntroduction.Related work is present in Section 2 and the proposed approach is shown in Section3. Experiments and results will be detailed in Section 4 andSection 5concludes withconclusion and future directions.

2. Methods

Based on the greenhouse dimensions, the monitoring of

[1] *Research Scholar, Computer Science, Sree Saraswathi Thyagaraja College, Pollachi, Tamil Nadu, India.*
vairamuthukaruppusamy@gmail.com, ORCID: 0000-0009-2955-6682
[2] *Assistant Professor, Computer Science, Sree Saraswathi Thyagaraja College, Pollachi, Tamil Nadu, India.*
krishna2c@gmail.com, ORCID: 0000-0003-2290-6957

temperature and humidityis identified with a number of sensors. One central node is used to monitor the water quality and controls the pump. The proposed system comprised with three nodes generally control unit (CU), environment unit (EU), and greenhouse unit (GU). GU is a greenhouse contains one CU as master node and a several EU as slave node based on the need of the greenhouse.

The CU master node utilises star topology to measure the water quality with the help of temperature, pH, EC and oxygen. The master node controls the pump for conserving the water and aggregates the sensed data from the slave nodes. It initialise serial and I2C communication that puts the microcontroller into sleep mode to preserve the energy. Sometimes the GSM shield is used in high power-consumption. The microcontroller is awake in the following situations:

1. Alarm_Interrupt– to signal irregular and possible harmful readings about temperature/ humidity and activate CU and GSM to inform the farmer through SMS/email.
2. Security_Interrupt–to signal unapproved access where the CU triggers the GSM and sends SMS/email to the farmer.
3. CU collects the quality of water sampling reading, activates GSM shield, wakes EN, and uploads to the server before sleep.
4. CU wakes up at fixed interval to activate the pump control based on water quality reading and decide on/off of water pump before returning to sleep.

3. Related Work

Hydroponic system fertilized and aerated the root of a plant through flowing nutrient water directly [4]. A common factorthat suppress the small-scale farmers is the flow of nutrient solution below the temperature might results in forming of pathogen. The pathogen development, suppress the root growth, but in hydroponics system Liebig's law is satisfied and nutrient is directly flow to root. This satisfaction leads to the high growth of crops and yield is also increased. This, new innovative and hi-tech system overcome the water scarcity and maintains nutrient level and better soil irrigation [5].

Soilless farming called hydroponics requires more space to grow plant and the system is not automated as the system is not suitable for small-scale people and growth rate also affected due to the requirement of huge human resources. Nowadays, the system enhanced to use less space with IoT and Big Data Analytics [6].

Pipelines are fixed to flow the water continuously. The whole system automates through microcontrollers to analyse the nutrient levels with good temperature and the pest factor to improve the economic growth of the farmer. An IoT framework proposed in [7] utilises a robotic system that reduce the usage of water upto 70% with minimum soil requirement. This work also verifies the nutrient level and utilises the sensor to absorb humidity, temperature and other supporting materials.

The vertical hydroponic system provides sustainable growth to small-scale farmers that supports to do the farming work with minimum work force.Though, in soil cultivation water consumption plays a vital role in agriculture, the hydroponic system requires $1/10^{th}$ of water utilised for normal irrigation [8]. More researches are proposed for healthcare [6-8], for communication between the vehicles [7,8] and for general sensor networks [7]. This hydroponic system checks the pH level, temperature, humidity and an electrical conductivity of a nutrient solution to prepare an effective solution for crop growth [9]. The products of the hydroponic system is highly sustainable than the classical one and disease detection of the crops is much easier in this hydroponic system through utilising IoT devices.

In [9] aims developing a hydroponic system for automated pH calibration. It uses pH sensor with a set of micro-pumps to pour liquid solutions and water to the nutrient solution. The main function of [10] is to detect the presence of a solution with pH value. The IoT based hydroponic system automatically adjust the water conductivity levels. This system uses HC-SR-4 sensor measures EC sensor, DHT11 sensor and water pumps. iPONICS system [10] controls water quality, temperature, dissolved oxygen level, electrical conductivity (EC), pH monitor, temperature and humidity monitor in the greenhouse. It warns the farmer or end-user about the exceed water quality, temperature or humidity than the predefined limit. This model experience a possible error of 0.93% in sensor reading and 0.1% in data transmission.

4. Proposed Work

Based on the greenhouse dimensions, the monitoring of temperature and humidityis identified with a number of sensors. One central node is used to monitor the water quality and controls the pump. The proposed system comprised with three nodes generally control unit (CU), environment unit (EU), and greenhouse unit (GU). GU is a greenhouse contains one CU as master node and a several EU as slave node based on the need of the greenhouse.

The CU master node utilises star topology to measure the water quality with the help of temperature, pH, EC and oxygen. The master node controls the pump for conserving the water and aggregates the sensed data from the slave nodes. It initialise serial and I2C communication that puts the microcontroller into sleep mode to preserve the energy. Sometimes the GSM shield is used in high power-consumption. The microcontroller is awake in the following situations:

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4. CU wakes up at fixed interval to activate the pump control based on water quality reading and decide on/off of water pump before returning to sleep.

EU consists of slave nodes that monitors the greenhouse environment such as temperature, humidity and so on. Thus, provides safe greenhouse to recover from hazards like fire. The system monitors the temperature every minutes but the readings stored in SD card. The proposed hydroponic system monitors the environment with minimal data transmission and power consumption. Number of EU for greenhouse is depend based on the dimensions. Each EU consists of own ID and address based on the proposed system.

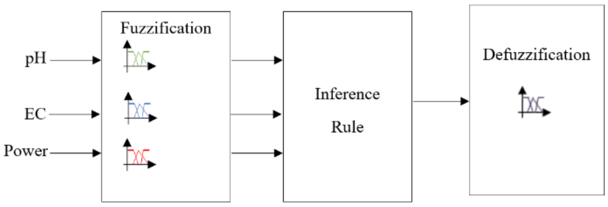
Fuzzy Inference System:

The proposed system utilizes Fuzzy Inference System (FIS) for better performance in hydroponics. To implement FIS, the sensor errors should be find and eradicate. Then, values of pH and EC should be find out for the plants planned to implement in hydroponicssuch as tomato (PC1), Cucumber (PC2), Strawberry (PC3), Banana (PC4), Spinach (PC5), Asparagus (PC6) and those values are detailed in Table 1.

Table 1. pH and EC values of planned plants [10].

Planned Crops	EC Value	pH Value
PC1	2.0-4.0	6.0-6.5
PC2	1.7-2.0	5.0-5.5
PC3	1.8-2.2	6.0
PC4	1.8-2.2	5.5-6.5
PC5	1.8-2.3	6.0-7.0
PC6	1.4-1.8	6.0-6.8

Based on the three inputs namely pH, EC and power supply the proposed FIS generates the process. This system determines the irrigation and available battery resources. Finally, this knowledge base system provides accurate nutrients to plants with less water through minimum energy.



The irrigation duration in hydroponics is calculated as in Eq. 1 [10].

$$t_i = \frac{Q \times 3600}{m \times q}(S) \quad (1)$$

If-Then rule is applicable as a traditional way of using fuzzy system to control the pump based on sensor readings for different parameters and for different plants. The below figure presents a proposed fuzzy membership functions to develop a better condition of a crop. EC and pH functions are determined and concentrates in improving the life of battery. Irrigation system works based on the provided Eq. 1 and when the FIS determines the received value is not appropriate then the previous valid values will be transmitted to FIS system and instruct the erroneous to the user. As per guidelines of hydroponics, three inputs used and three membership function is followed per input thus makes 27 rules. The forms of rules are shown in Table 2 with the following values Low (1), Medium (2) and High (3).

Table 2. Proposed FIS value.

pH	EC	Power	t_i
1	1	1	WEAK
1	1	2	VERY SHORT
1	1	3	SHORT
1	2	1	VERY SHORT
1	2	2	SHORT
1	2	3	ADEQUATE
1	3	1	SHORT
1	3	2	ADEQUATE
1	3	3	HIGH ADEQUATE
2	1	1	VERY SHORT
2	1	2	SHORT
2	1	3	VERY SHORT
2	2	1	SHORT
2	2	2	ADEQUATE
2	2	3	SHORT
2	3	1	ADEQUATE
2	3	2	HIGH ADEQUATE
2	3	3	DURABLE
3	1	1	SHORT
3	1	2	VERY SHORT
3	1	3	SHORT
3	2	1	ADEQUATE
3	2	2	SHORT
3	2	3	ADEQUATE
3	3	1	HIGH ADEQUATE
3	3	2	DURABLE
3	3	3	HIGH DURABLE

MQTT Broker:

Message Queuing Telemetry Transport (MQTT) is a lightweight protocol used in IoT. Lightweight characteristics and low overhead guarantees seamless data transfer with minimum bandwidth and decrease the consumption of CPU and RAM. Generally, it is a publish/subscribe protocol implemented in Raspberry pi to communicate.

IoT-enabled hydroponic system with the support of MQTT broker the data from a sensor is publish to the subscriber. The advantage of MQTT is as follows,

- MQTT broker reduces the network congestion and improves the network reliability by efficiently managing the data flow between the devices.
- It performs well in battery-placed and low-power devices such as sensors. Low-power IoT devices communicate and consume less network resources.
- It maintains a queue when the devices are offline and it transfers the messages after the devices are turned on as it maintains intermittent network connectivity.

The proposed system follows a quality of service (QoS) level 0 as a "fire and forget message" delivery to publish to the subscriber. The level 0 message doesnot recognize acknowledgement message and re-transmit when a failure message is received. Raspberry pi also acts as a controller to drive the actuator through TDS sensor.

Results:

The proposed system implements efficient hydroponic system through Raspberry pi with MQTT broker to obtain better average pH, less error and better energy consumption. To examine the performance, the proposed system is compared with the existing systems iPONICS [10] and auto_IoT[11]. The parameters used to verify the performance are average pH, energy consumption and error analysis under developing a spinach sample.

Average pH:

Average pH is used to identify the water ranged of 5-6 times a day. Spinach plants needs 5.5 to 7.0 pH range in hydroponics[6].

As spinach can tolerate to a moderate alkaline condition but it can grow best in acidic environment. Therefore, when a pH level is high or low then it leads to nutrient deficiencies and results in poor yields. The important in spinach growth is to adjust pH of nutrient solution to reach optimal growth. Figure 2 presents average pH level between the proposed and existing system.

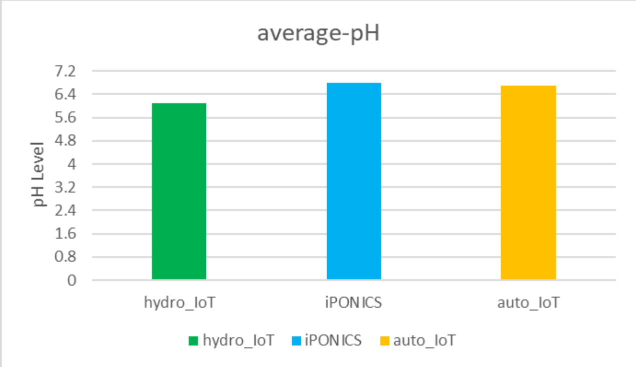


Fig 2. Average pH level

In figure 2, the proposed hydro_IoT achieves 6.2 as pH level, existing systems iPONICS maintains 6.7, and auto_IoT attains 6.8 as pH level. Thus, the hydro_IoT achieves lesser pH level and adequate pH level than the other systems. It improves the growth of spinach crops than the other two systems.

No Error Probability:

The parameter is to identity the "probability of no errors in one day". It is to identify the efficiency of the proposed work. This parameter presents the probability of no error/day based on single/multiple error, sensor error on pH, sensor error on EC, and sensor error on transmission. Figure 3 presents no error probability among the proposed and existing work.

The proposed hydro_IoT achieves better no error probability than the other works in single/multiple error (99%), sensor error on pH (99.4%), sensor error on EC (99.3%) and on 99.6% in transmission error whereas the proposed work maintains 19% of better no error probability than the existing works.

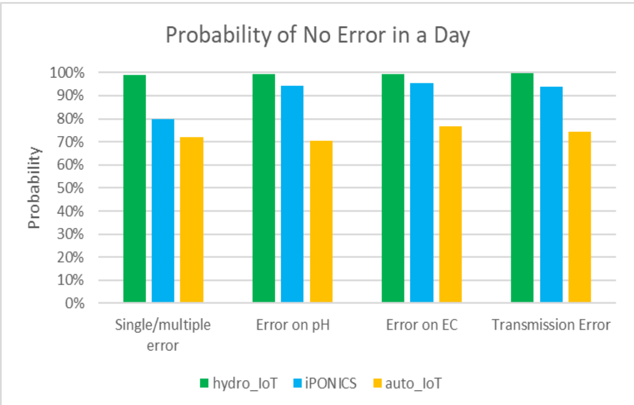


Fig 3. No Error Probability

Energy Consumption:

This parameter is used to checks the performance of the network life, where the whole system works on battery. The less energy consumption in all condition leads to better efficiency and improvement in lifetime of the hydroponics system. Figure 4 shows the energy consumption between the proposed and existing works.

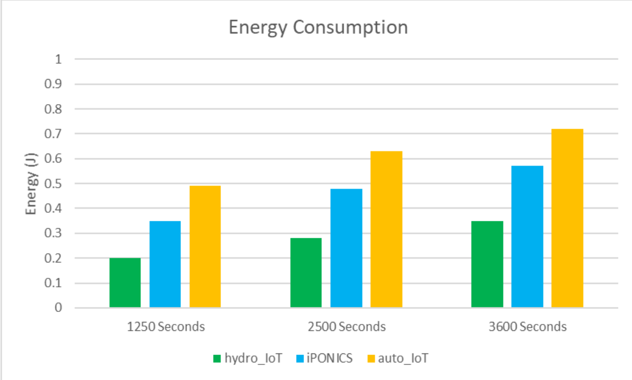


Fig 4. Energy Consumption

The above figure presents the energy consumption between the proposed hydro_IoT and other two existing approaches. For the complete 3600 Seconds, the plots are drawn for 1250 Seconds, 2500 Seconds and 3600 Seconds. In all three, the proposed hydro_IoT maintains less energy consumption upto 50% than the other two works. Thus, proves the proposed work hydro_IoT outperforms than the all other works and shows hydro_IoT a better model to implement in hydroponics system.

5. Results

The proposed system implements efficient hydroponic system through Raspberry pi with MQTT broker to obtain better average pH, less error and better energy consumption. To examine the performance, the proposed system is compared with the existing systems iPONICS and auto_IoT. The parameters used to verify the performance are average pH, energy consumption and error analysis under developing a spinach sample.

6. Discussion

A novel hydroponics system to monitor and control the system through IoT technology is introduced in this paper. Through monitoring the crucial parameters and controlling the pump to flow the nutrients to the plants this work is likely suitable to the hydroponic system. This system ensures the optimal growth of the plants through monitoring plants' environmental conditions, correct nutrient supply, automated flow of water and so on. This system is interconnected to various components, sensors, microcontrollers, MQTT broker to monitor the plant through smartphones or laptops. This system fulfills the food requirement of urban areas.Future work is to focus on two directions, First to improve the reliability through minimizing errors and faster analysis on condition of crops. Analysis on predicting nutrient values and water quality is a challenging problem in all applications. Developing a low cost budget free technology for small-scale farmers in urban areas may improve the development of more and healthy yields from less farm area that solve starvation of people.

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