Auto Indoor Hydroponics Plant Growth Chamber

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Abstract

The objective of this project is to build an auto indoor hydroponics plant growing chamber that has an auto monitoring and controlling system. A ESP32 based hydroponics electrical system is built with the attachment of hardware components such as temperature and humidity sensor, light intensity sensor, water level sensor, and water flow rate sensor. The software development of the system is through Arduino IoT Cloud platform, which has an overall suitability in terms of features, cost, and user intuitiveness for starters. Results have shown that ESP32 can ensure stable power supply. After testing and validation, all of the electrical components are stored in a power enclosure box to prevent contact with liquid. In short, the developed auto indoor hydroponics plant growth chamber has effectively demonstrated the ability in easing the plant cultivation procedure for agricultural community.

Keywords: Auto Indoor Hydroponics, ESP32, Controlling and Monitoring Hydroponics

1. Introduction

The global population is expected to reach 9.8 billion in 2050 [1]. Meanwhile, scientists anticipate that a growing population will result in a decline in the amount of available land. The scarcity of land in the future is predicted to become a bottleneck in all industries, but especially in agriculture [2]. Not to mention, a lack of available land will make traditional farming difficult and increase the likelihood of a food crisis due to rising food demand but low yield rates [3].

All the aforementioned issues have made it difficult to provide adequate and nutritious food, particularly in urban areas. Therefore, new methods of producing enough food must be developed in order to sustainably feed the world's expanding population. New and modern farming techniques marked a significant technological advance for humanity. The substitution of liquid as the new growing medium for traditional growing medium can be the different approach for consistent crop production, preservation of rapidly depleting land and food availability. On that being in case, the rapid growth of hydroponic system is getting attention and increasing widespread all over the world. It is accounted to have a world growth of 18.8% from 2017 to 2023 [4]. Hydroponics is derived from Greek word means Hydro "water" and Pons "labour". It is a method to grow various plants in water containing fertilizer without any soil by using different inert mediums such as sand, gravel, rockwool that act as a mechanical support [5]. The growth of hydroponics plants must be in a controlled environment and often affected by different parameters such as electrical conductivity in nutrients, nutrients circulation rate, PH, light intensity air and water temperature. Hence, the plant can have growth in an optimal condition with frequent monitoring for better yield rate of the plants [2].

Therefore, this project aims to develop an auto indoor hydroponic system prototype with "auto" monitoring and controlling features with IoT capabilities.

2. Literature Review

In this section, understanding and evaluating the monitoring and controlling systems from past research studies can be well understood.

2.1. Water and Nutrient Flow Path Monitoring and Controlling System

Water flow path and control takes a critical role in hydroponics system as the growth condition of plant was highly determined by the nutrients absorbed.

Fig.1. refers to the system used by M. E. H. Chowdhury et al., 2021 [6]. It contains two circulation paths: nutrient solution circulation and clean water supply.

The pump on the clean water source will only operate when the nutrient container does not meet the height of the water level with the aid of the water level sensor. The placement of the water level sensor was determined with the water height formula used; the water level sensor of the system will be placed 22.4cm vertically on the inner container to ensure enough 37L water in the tank.

An additional water flow sensor has been provided on the nutrient container. The water flow sensor was capable of measuring volume circulation per day and water. The system will notify when there is no water flow sensing.

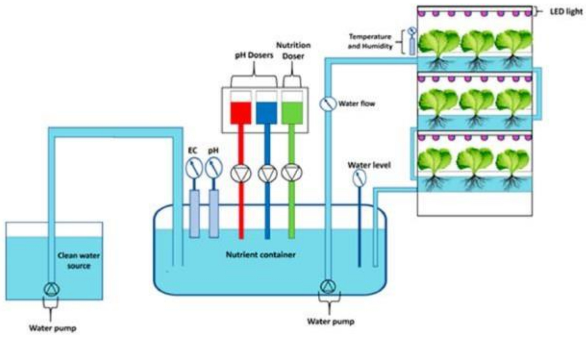

Fig. 1. Water, Nutrient and pH Monitor and Control System

2.2. Temperature and Humidity Monitoring and Controlling System

Temperature and Humidity around the plants is crucial as it may affect the growth of plants in different temperature environments.

Fig. 2. refers to the system used by S. Seni et al, 2020. [7]. It is an indoor hydroponics project in Malaysia that grow Pak Choy. There were two environmental sensors and two exhaust fans on each planting level on the system to ensure proper air circulation and detection. It's also observed that the reading of sensors values on different levels will be slightly different.

The temperature of the project is set within the allowable operating range of Pak Choy by implementing environment sensors and exhaust fans. The exhaust fans will be operating when exceed the allowable operating range. The project also identified that the temperatures will periodically rise in the afternoon that will cause continuous operation of exhaust fans in the afternoon.

Fig. 2. Temperature and Humidity Controlling System

2.3. Light Monitoring and Controlling System

Referring to another study about effects of Artificial Night LED Lighting by L. S. Wei et al, 2019, [8]. The proposed hydroponics system in Malaysia cultured the plant with a 18/6 (light/dark) photo period. Based on Table 1 below, it shows that the plant was cultured with 8hours of artificial lighting and 16 hours with natural lighting that continuously operate until plant maturity day.

Table 1. Light Duration Used in the Study

Natural Light without LEDs Support	Night-time without LEDs Support	Night-time with LEDs support
8am to 6pm	6pm to 12am	12am to 8am

2.4. IoT Monitoring System

Fig. 3**.** shows the overall system setup for the monitoring process. The proposed system is an Arduino Mega based hydroponic system with MQTT protocol to communicate between Arduino Mega and Node MCU for data processing. This system proposed precise monitoring of the nutrient solution's properties, such as electrical conductivity (EC), pH, and temperature, to ensure that the plants receive optimal levels of nutrients.The sensors result will then convert to JSON format and sent to cloud platform for monitoring. Overall, the proposed system is an important step forward in the field of hydroponics farming. It allows for precise and automated monitoring of nutrient solution levels reducing the need for manual labor of the farming process.

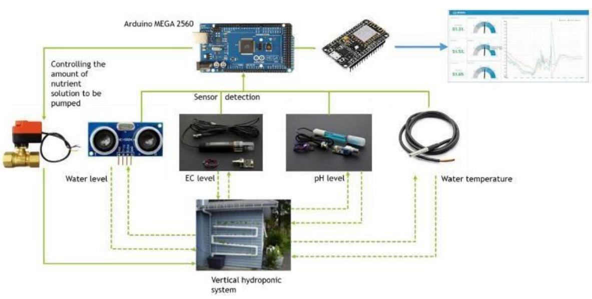

Fig. 3. IoT Monitoring Hydroponics System

3. Methodology and Setup

In this section, the monitoring and controlling systems from past research will be presented.

3.1. Mechanical Design and Setup

Fig. 4. shows the proposed hydroponics mechanical design with multiple main components. The hydroponic structure is arranged in a horizontal shape which has an overall dimension of around 1.25m x 0.79m x 1.2m (W x L x H) with 2 layers of planting platforms that can cover a total of 72 plants with 38 plants each layer. The system has additionally equipped with two ball valves that can help in controlling the water circulation and water level to void overflow piping [9]. The system has been installed in a chamber for easily controlled environments. The hydroponics system has mainly been using UPVC pipe as the structural material of the design for easily accessible, fabrication and assembly friendly as well as cost effective. Eventually, the chamber is also smaller in size as compared to a 160cm human being.

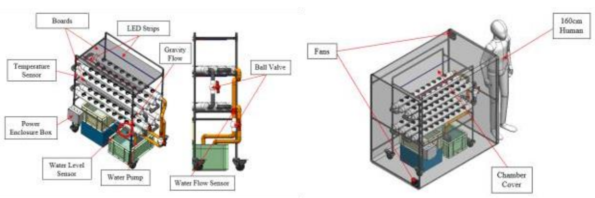

Fig. 4. Hydroponics Design with Main Components

3.2. Electrical System Infrastructure

Fig. 5. shows the proposed electrical schematic designed with Proteus. The proposed design has utilized ESP32 as the mainboard and different sensors such as the DHT11 for temperature and humidity sensing, the YF-S201 for water flow rate sensing, a water level sensor for nutrient level sensing, as well as light sensor module for light intensity sensing. Relays and actuating devices have been used to control the system automatically. In general, the total cost of components required to set up the system is about RM185.60

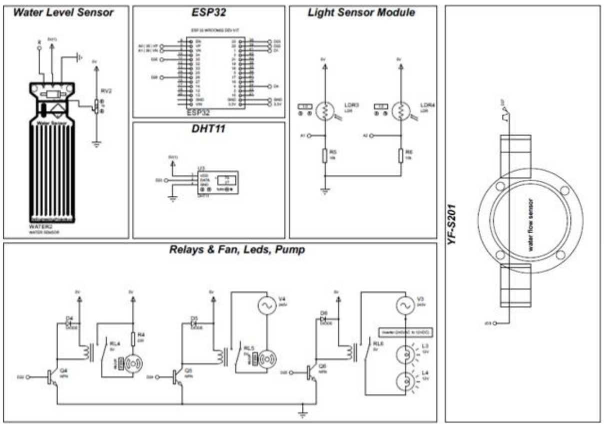

Fig. 5. IoT Monitoring Hydroponics System

3.3. Software System Flow

Ventilation Flow Chart

Fig. 6. shows the hydroponics system monitoring and control flow chart. The main controller, an ESP32, will retrieve data from the sensor, DHT11. The ventilation fan will turn on when the temperature have reached the threshold set, vice versa. Meanwhile, the main microcontroller will then publish that data to the Arduino cloud to allow real-time monitoring for the user.

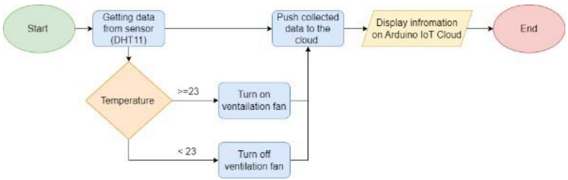

Fig. 6. Auto Ventilation Flow Chart

Grow Light Flow Chart

Fig. 7. shows the hydroponics system monitoring and control flow chart. The main controller, an ESP32, will retrieve data from the NTP servers and LDRs sensors. The LED strips will turn on when the time has reached the threshold set, vice versa. Meanwhile, the main microcontroller will then publish that data to the Arduino cloud to allow real-time monitoring for the user.

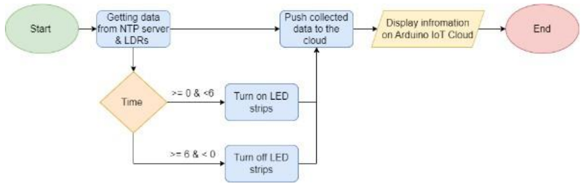

Fig. 7. Auto Grow Light Flow Chart

Nutrient Level and Water Flow Rate Flow Chart

Fig. 8. shows the hydroponics system monitoring and controlling flow chart. The main controller, an ESP32, will retrieve data from the water flow and water level sensors. The monitoring system will notify the user when the water level and water flow has reached the threshold set. Meanwhile, the main microcontroller will then publish that data to the Arduino cloud to allow real-time monitoring for the user.

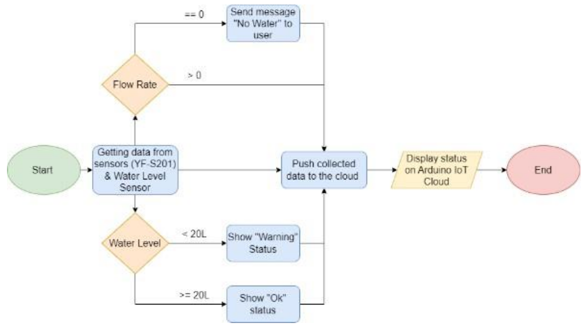

Fig. 8. Auto Grow Light Flow Chart

4. Results and Discussion

4.1. Testing, Analysis and Validation

Table 2 below shows the comparison of measured voltage and actual voltage of power supply pin on the microcontroller. The percentage error of most pins is within an acceptable range. However, the percentage error for the 3V pins is 10.33%, indicating that there is an issue with the expansion board. This might be due to the voltage drops across the pcb trace of the used expansion board. Nonetheless, since the measured voltages are 3.31V, it is possible that there is wrong labelling on the board. The 3V pins will be used as a 3.3V power supply to the system.

Table 2. Measured Voltage and Actual Voltage

Input	Pin Symbol	Measured Voltage (V)	Actual Voltage (V)	Percentage Error (%)
5V 2A	VIN	4.98	5.00	0.40
	5V (1)	4.92	5.00	1.60
	5V (2)	4.91	5.00	1.80
	3.3V	3.31	3.33	0.60
	3V (1)	3.31	3.00	10.33
	3V (2)	3.31	3.00	10.33

Temperature And Humidity Testing and Analysis

Table 3 and Table 4**,** Are showing the comparison of temperature and humidity of used sensor and measurement tools. The results are retrieved every 5 minutes until 30 minutes. Based on the results, it is observed that the temperature measurements have an average percentage difference of 1%. Nevertheless, humidity measurements have an average percentage of 3.53%. Both measurements are relatively acceptable.

Table 3. Measured and Actual Temperature

Input	No	Temperature (°C)		% Difference
		DHT 11 Sensor	Measuring Tool	
23°C	Initial Data	23.50	23.20	1.29
	Data at 5 Minutes	23.40	23.20	0.86
	Data at 10 Minutes	23.40	23.20	0.86
	Data at 15 Minutes	23.30	23.10	0.87
	Data at 20 Minutes	23.30	23.00	1.30
	Data at 30 Minutes	23.20	23.00	0.87
Average Error Percentage Difference (%)				1.00

Table 4. Measured and Actual Humidity

Input	No	Relative Humidity (%)		% Difference
		DHT 11 Sensor	Measuring Tool	
23°C	Initial Data	60	58	3.45
	Data at 5 Minutes	59	57	3.51
	Data at 10 Minutes	59	57	3.51
	Data at 15 Minutes	58	56	3.57
	Data at 20 Minutes	58	56	3.57
	Data at 30 Minutes	58	56	3.57
Average Error Percentage Difference (%)				3.53

Table 5 and Fig. 9 are for the Water Level Testing and Analysis. It shows the ADC reading of the water level sensor corresponding with the height of the measuring tools. The ADC input channels of ESP32 have a 12-bit resolution, this means that analog readings of 0 to 4095 shall be obtained. However, the measured value is only ranging from 0 to 2019 only, this might be due to the corrosion of the water level sensor. The testing results helped in benchmarking the operating range of the water level sensor. Therefore, the water level sensor can be used in this system for water level measurements.

Table 5. Comparison of Level Sensor and Ruler

No	Water Level Sensor (12-bit ADC Reading)	Measuring Tools (cm)
1	0	0
2	976	1
3	1454	2
4	1703	3
5	2019	4

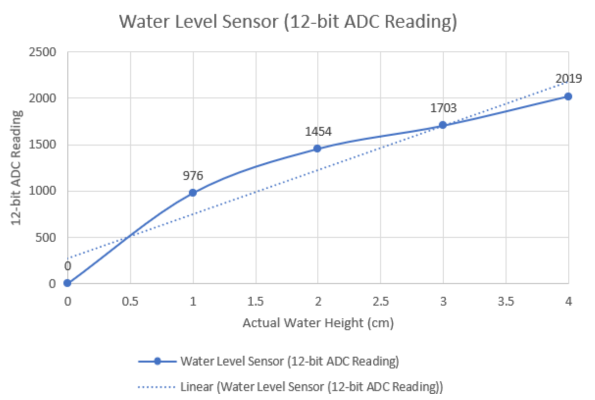

Fig. 9. Actual Water Height Correspond to 12-bit ADC

For the water flow rate sensor testing and analysis, a mathematical equation is used to calculate the flow rate of the system is as follows, [6].

$$Flow\ Rate\ (L/min) = \frac{Sensor\ Frequency\ (Hz)}{7.5}$$

Based on Fig. 10, the obtained data suggests a linear relationship between the valve angle of rotation and the water flow rate, this proves that the water flow rate increases with increasing the valve angle. The R^2 value of 0.9635 indicates that the data points are well- fitted to the linear regression line, indicating that the valve angle and water flow rate have a significant correlation.

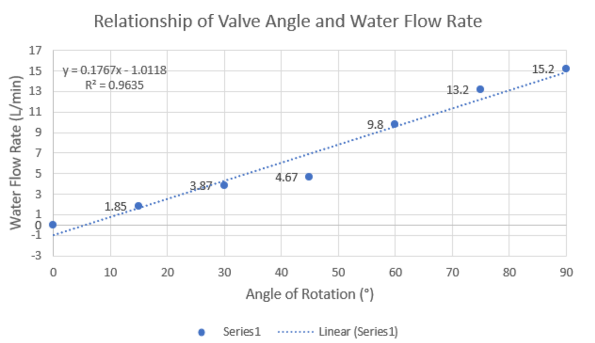

Fig. 10. Relationship of Valve Angle and Water Flow Rate

For the Light Intensity Testing, and based on the measurement conducted by comparing the light intensity sensor and lux meter in Table 5, it's identifying that the room lights itself is not enough to supply enough light intensity on the hydroponics system. The percentage difference of sensors and lux meter has less than 18% at different room conditions. It indicates that the light intensity sensor can be implemented in this prototype. Nevertheless, it's important to place the hydroponics system near a room that has exposure to sunlight for enough brightness for plants to conduct photosynthesis.

Table 5. Light Intensity Sensor and Lux Meter

Room Condition	Light Intensity Sensor (lux)		Lux Meter (lux)		% Difference	
	Top	Bottom	Top	Bottom	Top	Bottom
Sunlight	128.0	94.0	151.30	105.40	15.40%	10.82%
Room Lights	41.0	17.0	50.0	19.30	18.00%	11.92%
Without Lights	0	0	0	0	0%	0%

For the Relay Testing, Table 6 shows the results of controlling ventilation fan with relay, it is noticed that the ventilation fan will be turned on every afternoon. The fan will be turned off during mornings and nights. This is due to the reason that the ventilation fan will be turned on when reaching the state point.

Table 6. DHT11 and State of Fan

Threshold	Time (a.m. / p.m.)	Temperature of DHT 11 Sensor (℃)	State of Ventilation Fan (ON / OFF)
29.50℃	Morning 9 a.m.	25.40	OFF
	Afternoon 3 p.m.	30.30	ON
	Night 11 p.m.	27.80	OFF

Table 7 shows that the threshold was set, where the LED strips will be only turned on during 12 a.m. to 8 a.m. The LED strips will only turn on when it's midnight.

Table 7. Results of Time and State of LED

Threshold	Time (a.m. / p.m.)	State of LED Strips (ON / OFF)
12a.m. to 8a.m.	Morning 6 a.m.	ON
	Afternoon 12 p.m.	OFF
	Mid-night 1 a.m.	ON

4.2. Hardware Assembly and Implementation

Fig. 11. shows the detail of the placement of the electrical components. All the electronics components are placed in an enclosure to prevent direct contact with the water and easy for maintenance. The temperature sensor is located on the top layer of the hydroponics system. Meanwhile, there is also a light intensity sensor that is placed nearby. The second light intensity sensor is placed on the second layer. Next, the water flow rate and water level sensor are placed along the flow of circulation and inside the nutrient container. The ventilation fan is placed on the front of the chamber due to the reason that it can provide the lowest wire connection distance.

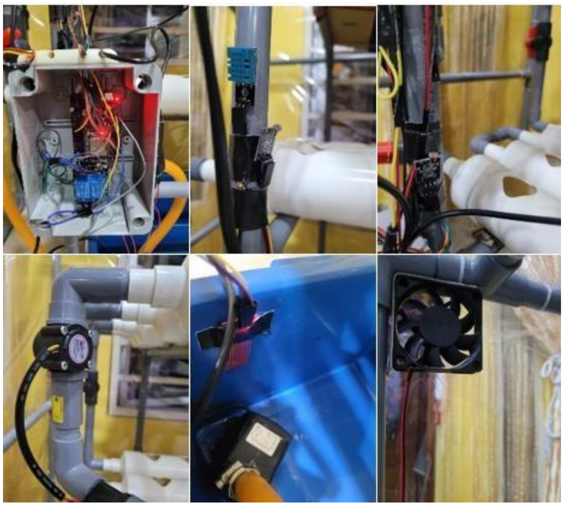

Fig. 11. Placement of Electrical Components

Final Implementation

Fig. 12. shows the final assembly of the hydroponics system. The assembly of the hydroponics system started with the structure, continued with circulation channels, chamber and finally electrical and electronics system.

Fig. 12. Mechanical Final Assembly

4.3. Software and Interface Implementation

Fig. 13. and Fig. 14. shows the Arduino IoT cloud dashboard and mobile app that measures the temperature, humidity, water flow rate, water level and light intensity on top and bottom layer. There is only one page of the dashboard and app interface of the system for user friendliness. The top part of the interface shows the measurement values and status of sensors in real time. Meanwhile, the bottom part of the interface shows the measurement values retrieved over time.

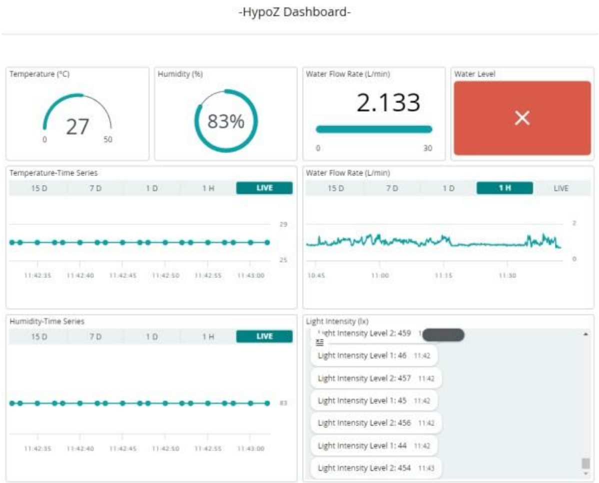

Fig. 13. Web Interface of Arduino IoT Cloud System

Fig. 14. App Interface of Arduino IoT Cloud System

4.4. *Hydroponic System Comparison*

Table 8 shows two different similar commercial solutions as compared to the proposed system which are all solutions to indoor agriculture. It can be seen obviously that the proposed system offers more features with a monitoring and controlling system. Yet, remaining significantly cheaper and affordable to anybody to venture into agriculture.

Besides that, the proposed system has a medium power consumption as compared to the Grow IT premium kit. This indicates that the system has consumed less energy and power.

In general, the proposed system provides a cheaper and more features alternative for indoor farming, which is also suitable for growers that just started to venture into agriculture.

Table 8. Comparison of Hydroponics System

Similar Work or Commercial Solution	 HypoZ	 City Vertical Farm L	 GrowIT Premium Kit
Plant Capacity	72	48	70
Volume	1.19 m^3	1.48 m^3	1.31 m^3
IoT Solution	Yes	None	None
Light Monitoring	Yes	None	None
Temperature Monitoring (M) and Control (C)	M and C	None	None
pH Monitoring (M) and Control (C)	None	None	None
Power Consumption	58.665 W	18 W	120 W
Price Information	RM 700.07	RM 2899.00	RM 2999.00
Vendor	Self Developed	CityFarm	GrowEatWell

5. Conclusion

The designed and tested prototype has shown successful results in achieving the objectives of this project. There is still room for improvements. It is recommended that the hydroponics structure can be attached with additional features such as air- conditioning and humidity controlling devices to effectively control the growing environment of the plants. Besides, features like pH and EC monitoring and controlling devices can be equipped, this may help to adjust accurately nutrient solutions up taken by the plants.

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