

Development of An Automated Hydroponic System for Leafy Vegetables

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DOI: <https://doi.org/10.47772/IJRISS.2026.100800859>

Received: 5 September 2026; Accepted: 9 September 2026; Published: 19 September 2026

ABSTRACT

With the increasing demand for sustainable and efficient agricultural practices, hydroponics has emerged as a promising solution for cultivating crops in controlled environments. However, traditional hydroponic systems can be time-consuming and labor-intensive. To address these challenges, an automated hydroponic system using Arduino UNO and NodeMCU is developed. The objectives of this paper are to develop an automated hydroponic system for leafy vegetables and monitor the growth of the leafy vegetables with the system developed. The scopes of this project focused on planting leafy vegetables hydroponically using NFT. The system incorporates sensors to continuously monitor the crucial parameters that are important for hydroponics such as TDS value, pH value and water level of the nutrient water. Additionally, the automated hydroponic system incorporates remote monitoring and control capabilities through the implementation of IoT application using Blynk. In this project, this automated hydroponic system shows significant advantages over manual control of hydroponics since yield is increased with 10.28kg/m² where the weight per plant is from 82.3g to 91.2g, enabling labour requirement to be reduced.

Keywords: Hydroponic, Arduino UNO, NodeMCU, IoT application

INTRODUCTION

As stated by World Food Programme (WFP) [1], in only two years, the number of people facing, or at risk of, acute food insecurity increased from 135 million in 53 countries pre-pandemic, to 345 million in 82 countries today. Hence, self-sufficiency in the local agricultural sector is very important especially now when the impending global food crisis happened which caused the food price to shoot up. According to economist Geoffrey William in Malaysia Now [2], the preparation of Malaysia to face the food crisis is not enough since Malaysia still imports 60% of its food needs. Therefore, the idea of self-sustainability farms started to emerge as an idea among the people living in the country to ensure the availability of fresh vegetables and food security for the near future [3]. On the other hand, hydroponics is one of the technologies developed to increase yield and enhance the growth of vegetable with only limited space. By letting the people to produce their own vegetable using hydroponics, it might be a solution against food crisis. The objectives of this paper are to develop an automated hydroponic system for leafy vegetables and monitor the growth of the leafy vegetables with the system developed. The scopes of this project focused on planting leafy vegetables hydroponically using NFT, and control the variables.

The world population projected to reach 9.7 billion by 2050 and 50% of the arable land around the world is estimated to be unusable for farming according to United Nations Organization [4]. In order to overcome this problem where the food demand can be reached, the food production need to be increased by 110%. Such problems highlight the importance of hydroponics and its advantages as well as its benefits.

Hydroponics is the practice of growing plants using only water, nutrients, and a growing medium without using soil [5]. There are many types of hydroponic systems. It can be either active or passive. Active hydroponic system means the system will recirculate the nutrient water in the system usually by pump. On the other hand, passive hydroponic system relies on a wick or the anchor of the growing media [6]. Beside active

and passive, hydroponic system can also be categorized into recovery or non-recovery system, where recovery system will reuse the nutrient solution while non-recovery applies the nutrient solution to the growing media without recirculate. Basically, there are 6 types of hydroponic system which are Nutrient Film Technique(NFT) system, Deep Water Culture(DWC) system, wick system, Ebb and Flow system or Flood and Drain system, drip system and lastly aeroponic system. hydroponic cultivation method allows higher crop yield and high-quality products, even in areas with adverse growing conditions [7]. According to Gina Harper [8], the yield from hydroponic are 20-25% more than soil-grown yield. The growth rate of crops grown hydroponically also higher due to the abundance of oxygen in the nutrient-charge solution. Based on Amanda Brahlek [9], higher oxygen level stimulates root growth and enhance nutrient uptake, giving a more bountiful harvest.

Table 1: Yield comparisons between hydroponic and open field cultivation [19]

Parameters	Hydroponic system production (kg/ha)	Open-field production (kg/ha)
Rice	13,456.56	841.03 – 1009.25
Maize	8971.0	1682.07
Peas	15,699.32	2242.76
Tomato	403,335.81	11,203.75 – 22,407.47
Potato	156,852.29	17,925.98
Cabbage	20,184.84	14,577.94
Cucumber	31,398.64	7849.66
Lettuce	23,548.98	10.092.42

METHODOLOGY

The project is started from the literature review in order to identify the problem definition. Not only the problem definition, the parameters need to be controlled by the automated hydroponic system will be identified from the literature review which included the TDS value, pH value and water level. Some of the function also need to be identified, such as Serial communication, the implementation of IoT for real-time monitoring and remote control of the actuators, also the data logging function into a MicroSD card to back up and save all the data. After identifying the function, the hardware and software of the automated hydroponic system are developed. For the hardware, the frame will be construct first followed by the growing site, water circulation system and control system. At the same time, the algorithm of automated hydroponic system is developed also for the Arduino UNO and NodeMCU.

After completing the hardware and software, all the components are assembled and integrated with the coding. The analog sensors such as TDS and pH sensor will be calibrated for accurate result, same for each peristaltic pump to determine the flow rate. Before the data collection, seedling preparation will be done to prepare the seedling of dwarf bok choy to be grown in the system developed. After that, data collection will be started as soon as the seedlings are moved to the growing site. All the data like TDS, pH, water level and water temperature will be displayed and saved in MicroSD card. The height and the numbers of leaves of each dwarf bok choy will be recorded each week. During harvesting, measurement of weight will be done on the fresh shoot weight(FSW) and the fresh root weight(FRW) to illustrate the yield. After getting the result, the discussion and conclusion will be done.

Overall System Description

The block diagram of braille notetaker is shown in Figure 1. an Arduino Uno will serve as the microcontroller. Various sensors, including a TDS sensor, pH sensor, ultrasonic sensor, and temperature sensor, will be installed in the nutrient water reservoir tank. The TDS sensor will measure the EC and TDS of the nutrient water to ensure the proper concentration of fertilizer. The pH sensor will measure the pH value of the nutrient water. The ultrasonic sensor will serve as an indicator for measuring the water level in the reservoir tank. The temperature sensor will measure the temperature of the nutrient water, which is necessary for temperature compensation when measuring EC and TDS values. The Arduino Uno will receive data from all these sensors. The TDS and pH sensors are analog sensors, while the ultrasonic sensor and temperature sensor are digital sensors. The sensor values received by the Arduino Uno will be displayed on an LCD display. If any of the sensor values exceed the predefined upper or lower threshold limits, the Arduino Uno will send a signal to the corresponding actuator connected to a 5V relay. For example, if the water level is low, the relay will activate the water pump. Four peristaltic pumps will be used to pump fertilizer A, fertilizer B, pH up, and pH down solutions, respectively. Additionally, a submersible water pump will be installed in the water storage tank to circulate the water. These actuators will control parameters such as water level, TDS value, and pH value, keeping them within the optimum range. For IoT applications, the Arduino Uno will establish serial communication with a NodeMCU. Once the NodeMCU receives sensor data from the Arduino Uno, it will send the data to the Blynk application for real-time graph plotting and display of all the measured values. Furthermore, the Blynk application will include push-button widgets for manual control of the relays. In case the NodeMCU loses connection with the Blynk application, the sensor data will not be saved. To address this, a real-time clock (RTC) module with a MicroSD card adapter will be added to the Arduino Uno, allowing the data to be logged onto a MicroSD card.

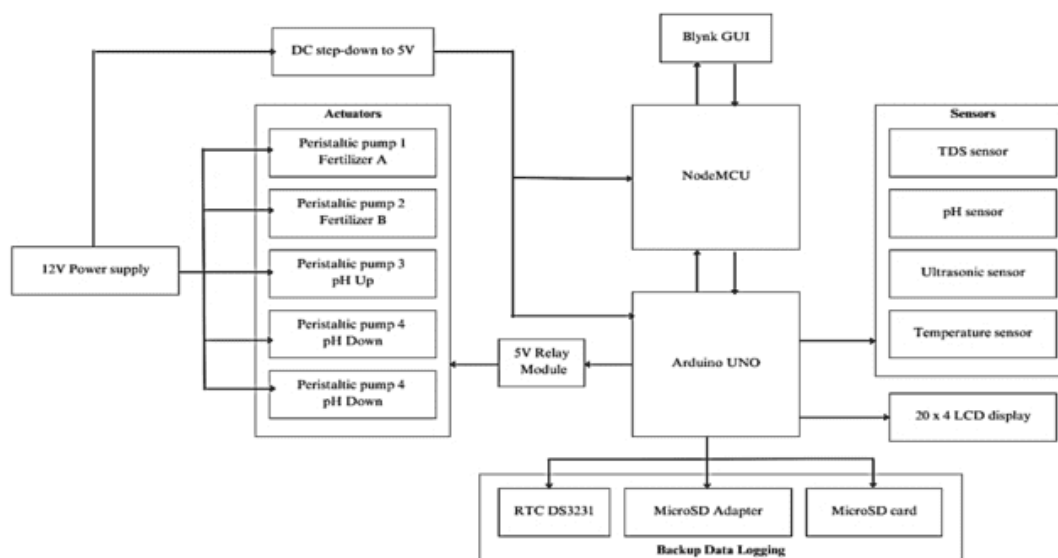


Figure 1: The block diagram of automated hydroponic system.

Hardware Development

The hardware development of the frame is done by cutting both 20mm outer diameter(OD) PVC pipe and 25mm outer diameter(OD) PVC pipe into suitable length. The frame will be separate into upper and lower part where upper part is for mounting the full spectrum LED grow light while the lower part is to act as the base and at the same time support the growing site. The upper frame will be made using 20mm OD pipe while the lower frame will be made using 25mm OD pipe. The pipe will be connected with 3-way connectors for the upper frame while 4-way connectors will be used for the lower frame. The upper frame will then connect to the lower frame by slide into the open end of the 4-way connectors forming a telescopic joint. After the whole frame is constructed, the mounting brackets will be screwed on the upper frame to hold the LED grow light as shown in Figure 2(b).

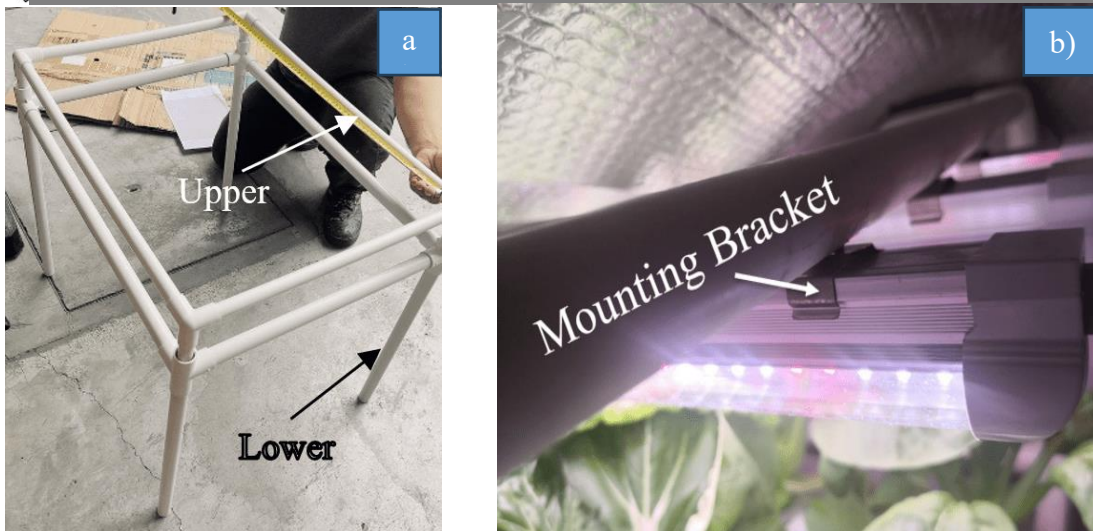


Figure 2: (a)Frame and (b)Mounting of Grow Light.

For the growing site of the hydroponic system, 82mm OD diameter uPVC pipe will be used. Two 60cm pipes will be cut where both ends of the pipes will be enclosed with end caps. To avoid leaking at the end caps, it will be glued using PVC pipe cement. Four holes with 32mm diameter will be drilled using a step drill bit for each pipe to act as the exact location to place the net cup where a distance of 15 cm between centre of each holes for an optimum plant density to get a better yield. Elbow connector for 16mm OD polyethylene pipe is installed at end caps of both ends to act as the water inlet and water outlet. Also, to avoid leaking, the installation will be using rubber grommet.



Figure 3: Construction of Growing Site.

After both of the uPVC pipe is completely fabricated, both of it will be installed on the lower frame by fix it using a zip tie where the distance between the two pipes will be 15cm. The next step is complete the nutrient water circulation system using polyethylene pipe where the inlet will be connected to the water pump and the outlet will be directed to the nutrient water reservoir tank. For one of the outlet, it will go through the sampling point first before entering the tank for data acquisition. Both of the reservoir tanks will also be modified by adding some holes on the cover for the installation of inlet and outlet of nutrient water, ultrasonic sensor, sampling point and the inlet for refill water and controlling solutions such as fertilizer A, fertilizer B, pH up and pH down.

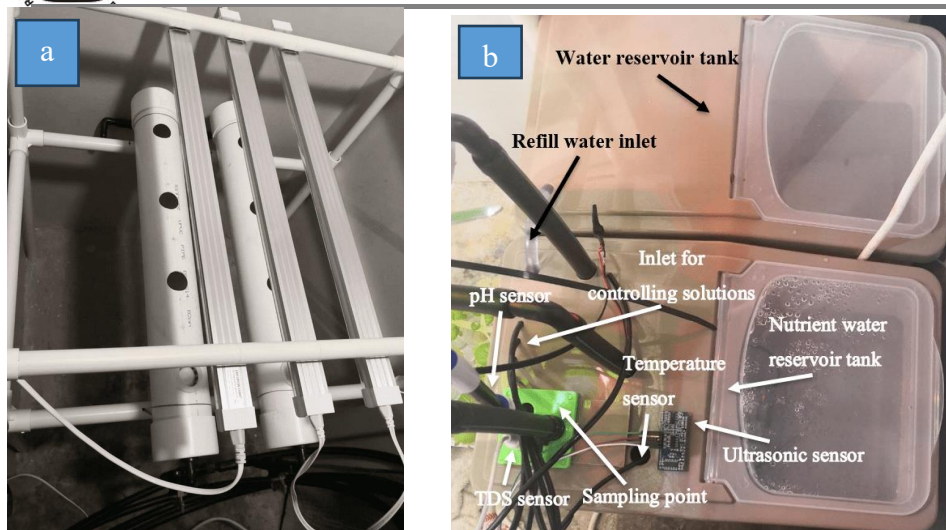


Figure 4: Arrangement of the (a) Growing Site and (b) Modified Reservoir Tanks

The hardware of the control system is developed by using a 16 x 16 cm electronic box to place the electronic circuit. An 3D printed plate is used as the platform to fix all the electronic components with PCB standoffs and screws. The wiring of the electronic circuit will be following the schematic diagram drawn using fritzing software. Fixing the 3D printed peristaltic pump holder and bottle holder to the electronic box, the peristaltic pumps and the bottles can also be installed.

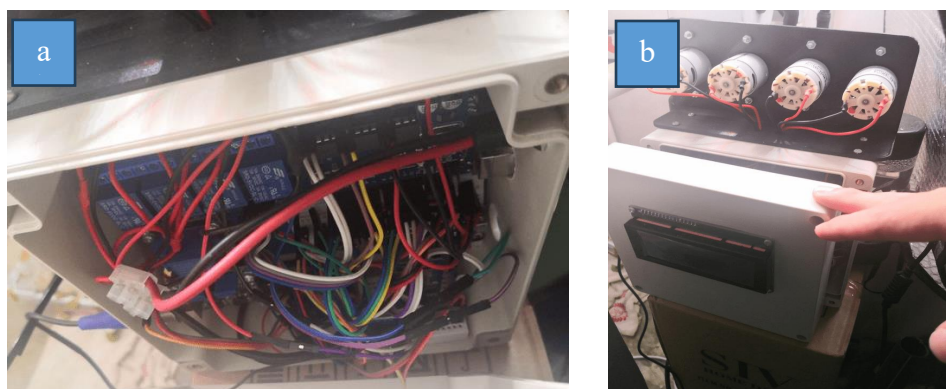


Figure 5: (a) Electronic Circuit and (b) Overall Control System

The overall hardware for the NFT hydroponic system is shown in Figure 6. Followed by the labelled model and connection of circuit in Figure 7 and 8 respectively.



Figure 6: Overall Hardware for the NFT Hydroponic System

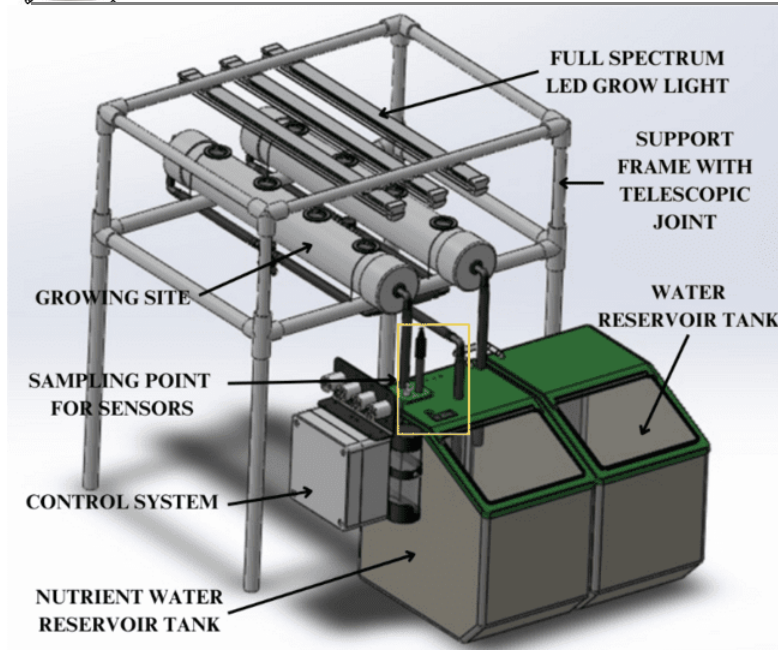


Figure 7: SOLIDWORKS Model(labelled)

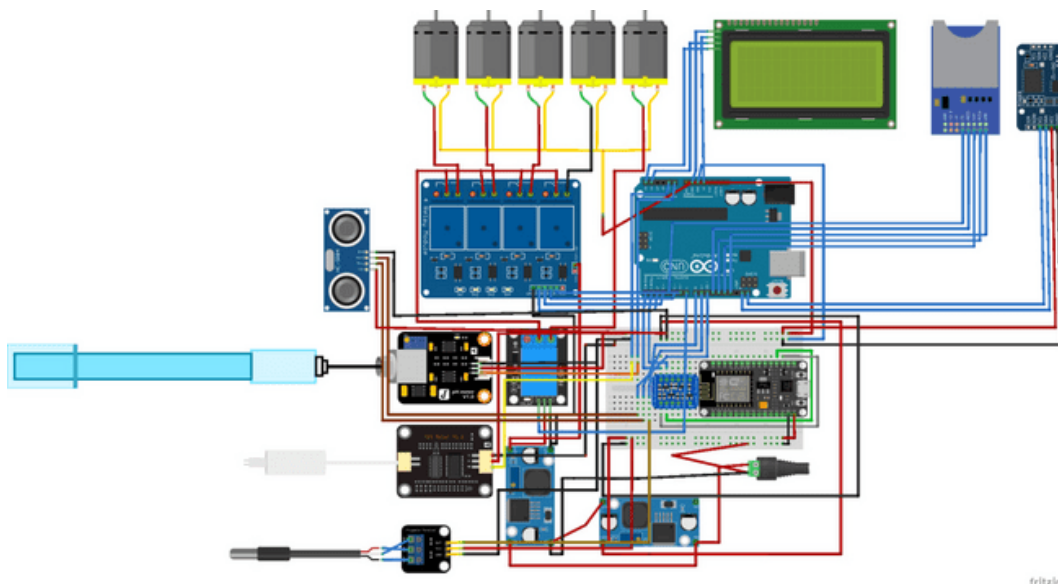


Figure 8: Connection Diagram of Control System

Software Development

Software development of the system is done using the Arduino IDE. The coding needs to be separated into two parts which are for Arduino UNO and NodeMCU followed the algorithm planned. Arduino UNO is used for the general function of the control system while the NodeMCU is used as the application of IoT.

Before complete the coding, the sensors need to be calibrated so that the values obtained is accurate and precise. The sensors that need to be calibrated is the analog sensors which are TDS sensor and pH sensor. Besides the analog sensor, each of the peristaltic pump also needs to be calibrated to know the flow rate.

Algorithm Development

Algorithm of Arduino UNO and NodeMCU is shown in the Figure 8, 9 and 10 respectively.

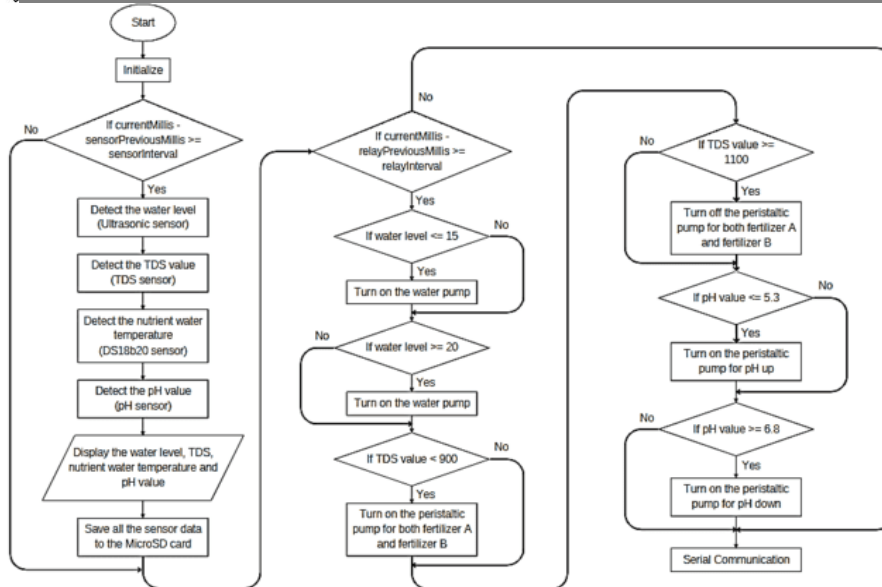


Figure 8: Flowchart of Arduino UNO

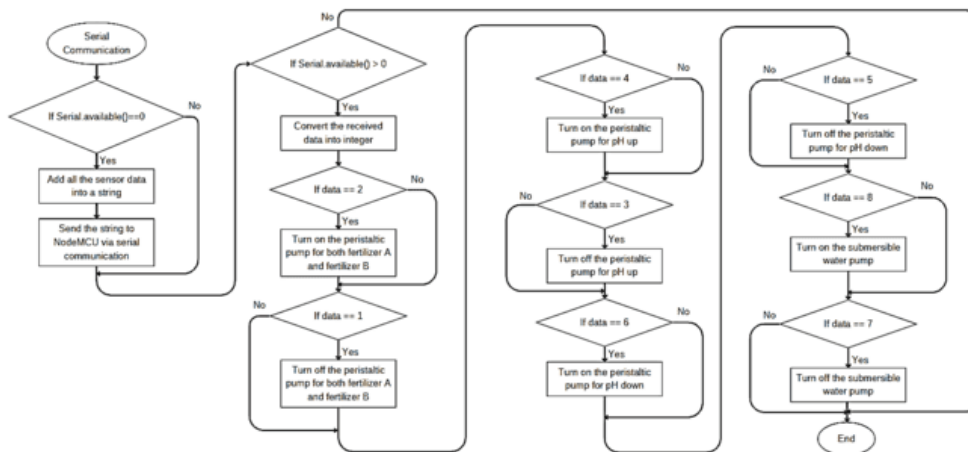


Figure 9: Flowchart of Arduino UNO(serial communication)

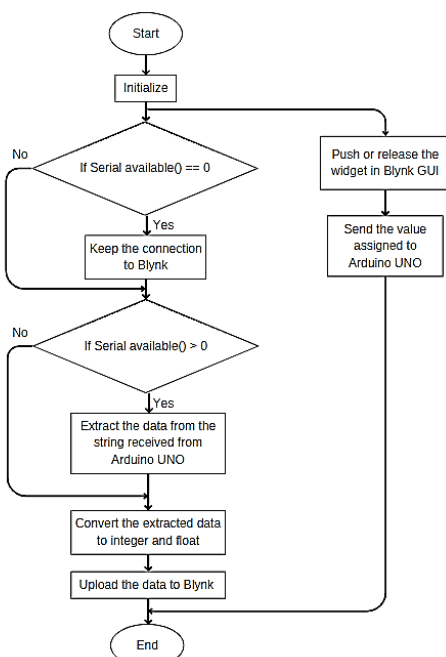


Figure 9: Flowchart of NodeMCU

Seedlings Preparation

For the seedling preparation, the first stage is to germinate the seeding. To start, hydroponic sponges need to be rinse through the water and soaked until it is fully absorbed with water. Once the sponges are soaked, the sponges can be placed on a seedling tray to plant the seeds. The seeds are planted by putting the seed in the dent at the middle of the sponge. Then, close the plastic cover of the seedling tray to ensure the high humidity inside trigger the seeds to germinate.

The seeds will germinate in one week. After germination, the seedlings will be remaining in the seedling tray for 2 weeks to be planted into the hydroponic system. In the hydroponic system, the plants will be grown until harvest. Dwarf bok choy is ready to harvest after 30 days.



Figure 8: 2nd Week After Germination.

RESULT AND DISCUSSION

Results for the developed system are presented in terms of accuracy test, sensor data, the functionality of the IoT application and the system as well as the growth of the plants.

Accuracy test

The accuracy test is important to show how well the sensors or peristaltic pumps are calibrated. A well calibrated sensor ensures the functionality of the system by providing accurate and reliable measurement. On the other hand, a well calibrated peristaltic pump will always give the exact volume same as the desired volume output.

The accuracy test of TDS sensor will be comparing the TDS value measured by the TDS sensor with the TDS meter that exist in the market. The value measured from the TDS meter will be determined as actual value to calculate the percentage error of TDS sensor calibrated. 10 different TDS will be prepared by adding the fertilizer A and fertilizer B into 1.5 litres of water.

Table 2: Accuracy Test for the TDS Sensor

No.	Fertilizer A Added (ml)	Fertilizer B Added (ml)	TDS Value Measured (ppm)		Percentage Error (%)
			Sensor	Meter	
1	0	0	72	75	96.00
2	5	5	231	237	97.47

3	10	10	530	524	98.85
4	15	15	748	752	99.47
5	20	20	903	908	99.45
Average %error:					98.25

Similar to the TDS sensor, the accuracy test of pH sensor is to compare the pH value measured with the pH meter available in the market. The value measured from the pH meter will be determined as actual value to calculate the percentage error of pH sensor calibrated. 10 different pH will be prepared by changing the pH randomly adding the pH up and pH down with 1.5 litres of water.

Table 3: Accuracy Test for the pH Sensor

No.	pH Value Measured (ppm)		Accuracy (%)
	Sensor	Meter	
1	7.73	7.95	97.23
2	3.31	3.36	98.51
3	6.47	6.54	98.93
4	8.94	9.14	97.81
5	12.45	12.57	99.05
Average Accuracy:			98.31

Calibration is done for each of the peristaltic pump since each of the pump has different flow rate. After the calibration of peristaltic pump, the accuracy is basically 100%. All of the linear calibration graphs of the peristaltic pumps are shown in the figures below where from the linear calibration graphs of the four peristaltic pumps, the peristaltic pump for fertilizer A has the highest flow rate of 1.5152ml/s followed by peristaltic pump for fertilizer B, pH down and pH up with 1.3889ml/s, 1.2821ml/s and 1.25ml/s respectively.

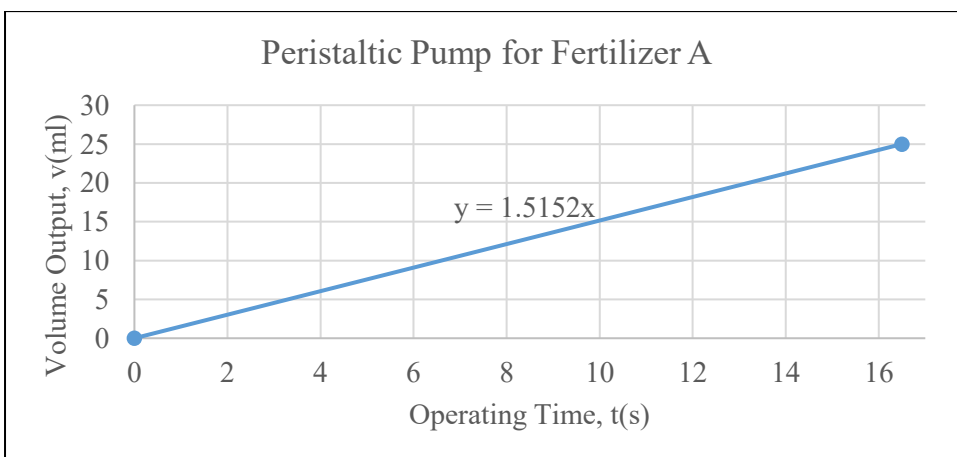


Figure 9: Graph of Volume Output Against Operating Time(Fertilizer A).

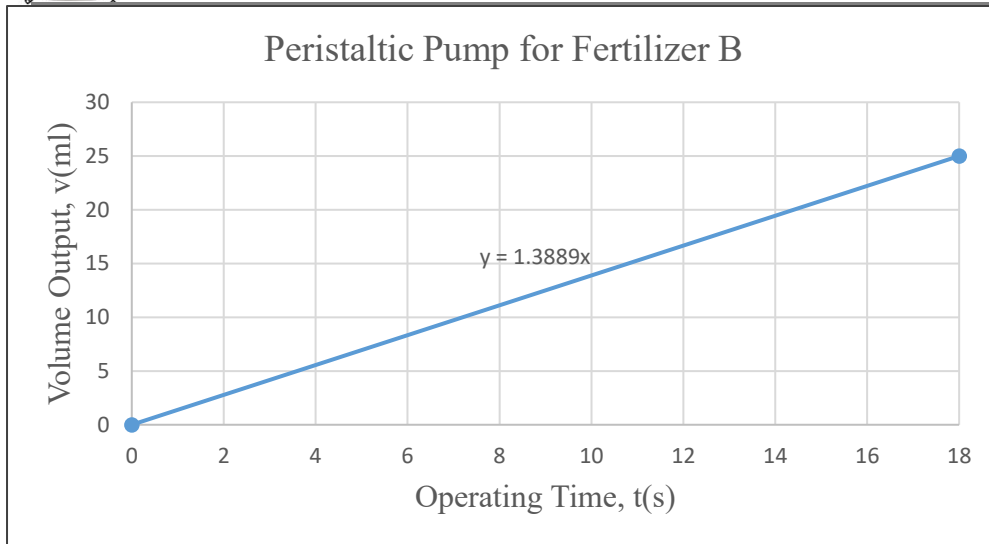


Figure 10: Graph of Volume Output Against Operating Time(Fertilizer B).

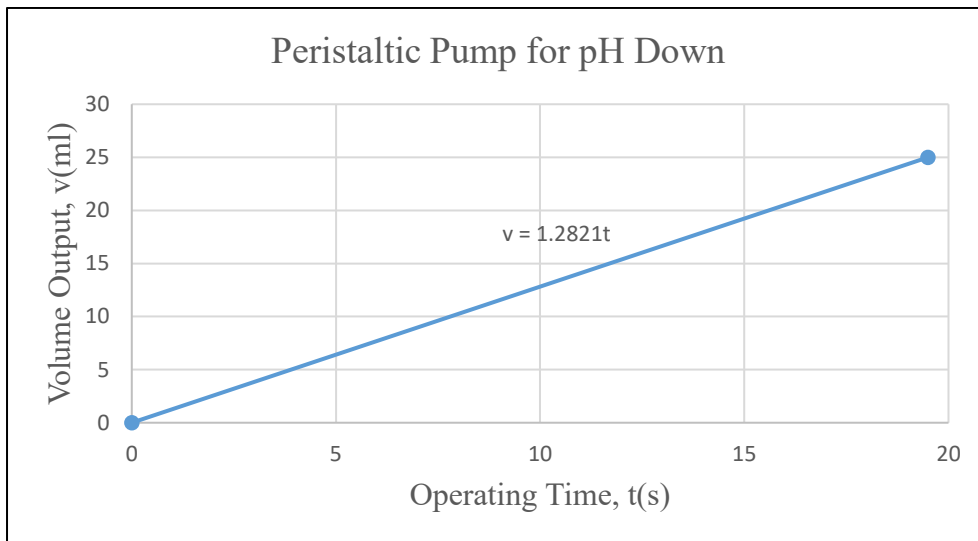


Figure 11: Graph of Volume Output Against Operating Time(pH Down).

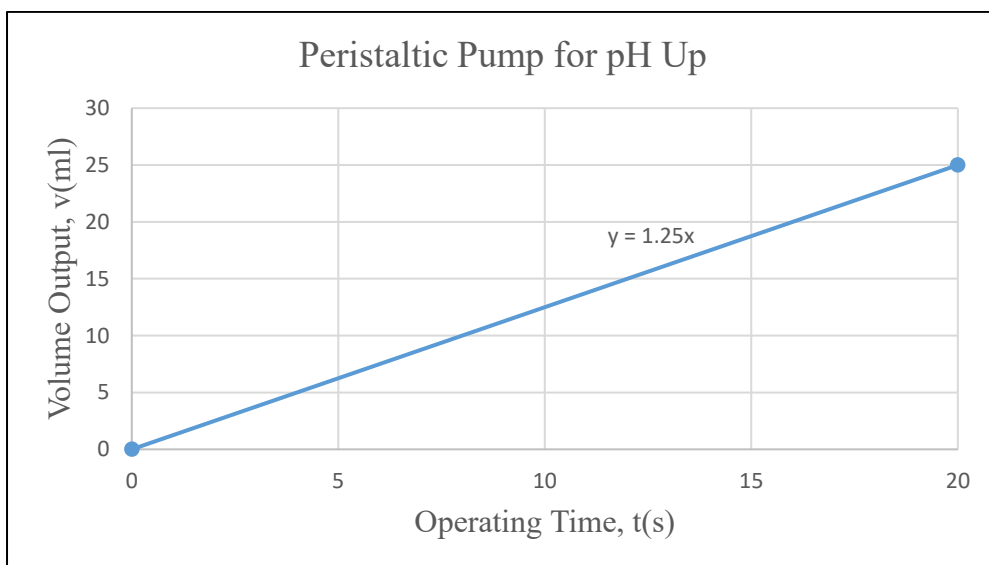


Figure 12: Graph of Volume Output Against Operating Time(pH Up).

Sensor Data

The sensor data is all saved in the MicroSD card with the specific time, the 30 days data file is enormous while converting it from text file into excel because the sensor data will be saved once per 10 seconds using the millis() function making the data file to be very big. To make the analyse the data, it needs to be extracted, and filtered the large amounts of data in Excel into a more manageable quantity. To have a more precise analysis, data in 1 day is chosen to be analysed. The TDS value is initially set to a desired range of 900-1100ppm based on the optimum TDS for dwarf bok choy. The initial TDS value of the nutrient water can be seen to be below the threshold range because of adding of water to the nutrient reservoir tank so the push button is used to increase the TDS value rapidly. After the manual interference, the system just maintaining the system automatically without letting the TDS value to be outside of the desired range, showing the stability of the system.

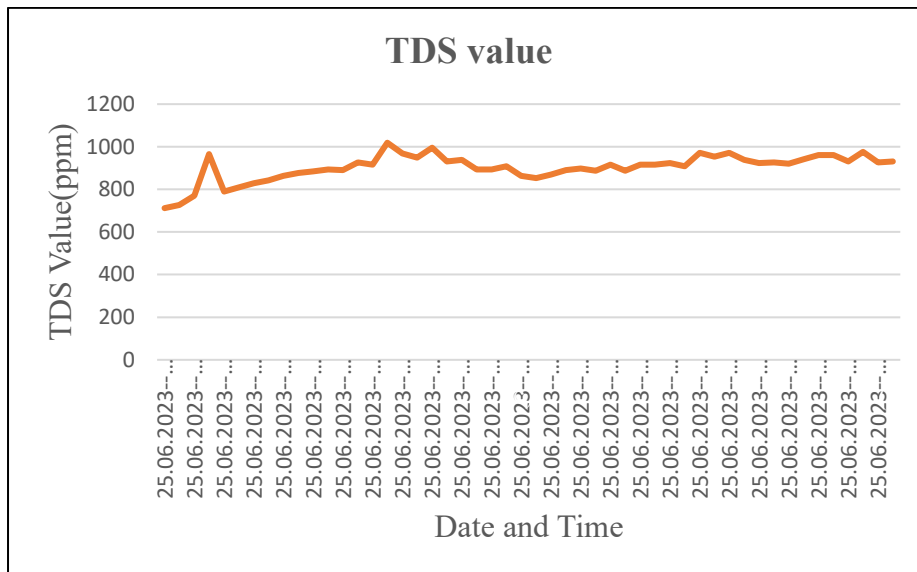


Figure 13: Graph of TDS Value in 1 Day

For the pH value, data in 25 June 2023 is extracted and the graph is shown in Figure 4.11. The pH value is initially determined with a threshold range of pH5.3-6.8 according to the optimum pH of dwarf bok choy. Initially, the pH is at 5.4 where the adding of water increase the pH value. The system control the pH value steadily until at one point the adding of water cause the pH value to be exceed the upper threshold limit, reaching pH7 which trigger the system to add in the pH down to ensure that the pH is in optimum range.

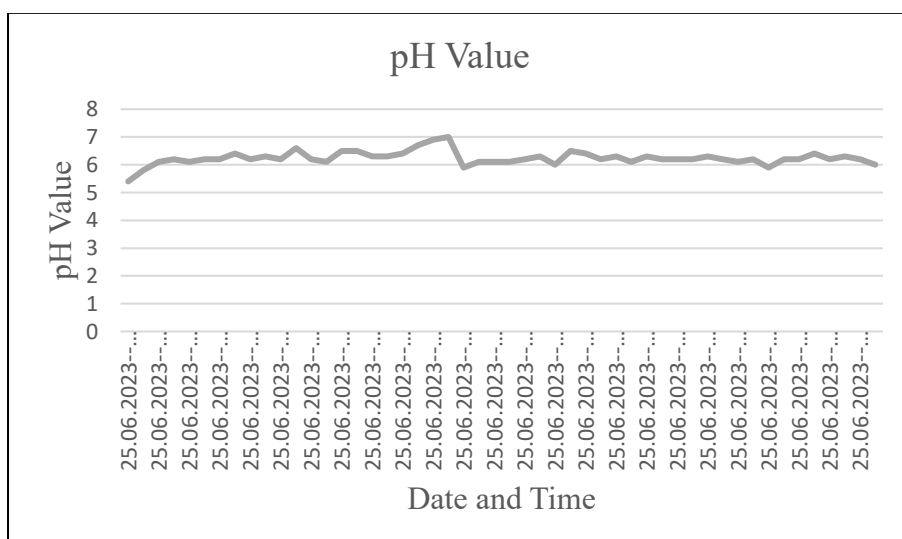


Figure 14: Graph of pH Value in 1 Day

As for the water level, the data in 25 June 2023 is extracted and the graph is shown in Figure 4.12. The threshold range of water level is set to be below 20cm and higher than 15cm. At the beginning, since the water level is below than the lower limit, the control system is triggered to switch on the pump in the water reservoir tank, increase the water level. From the graph, it is clearly shown that the control system can control the water level efficiently ensure that the nutrient water is always sufficient.

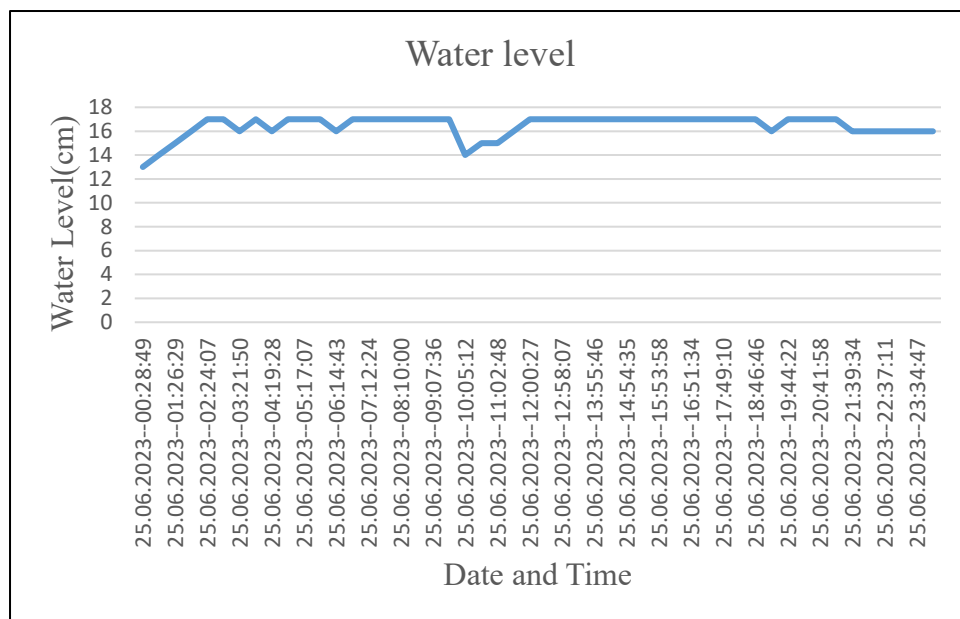


Figure 15: Graph of Water Level in 1 Day

Functionality of the IoT Application

The IoT application is well implemented into the hydroponic system. The NodeMCU can successfully upload the sensor data to Blynk application and display it using the gauge widget as shown in the Figure. All the sensor data are accurately displayed and in sync with the data displayed on the 20x4 LCD. Beside the gauge widget used, the data is plotted on a graph for TDS value, pH value, water level and water temperature to illustrate the system's stability, enabling the user's real-time monitoring. Also, there are three push buttons in the Blynk GUI to control the peristaltic pump manually if the value measured is not reaching the desired value. There are two platforms used for the Blynk which are online web dashboard and application in phone. The GUI of Blynk for both web dashboard and phone are shown below.

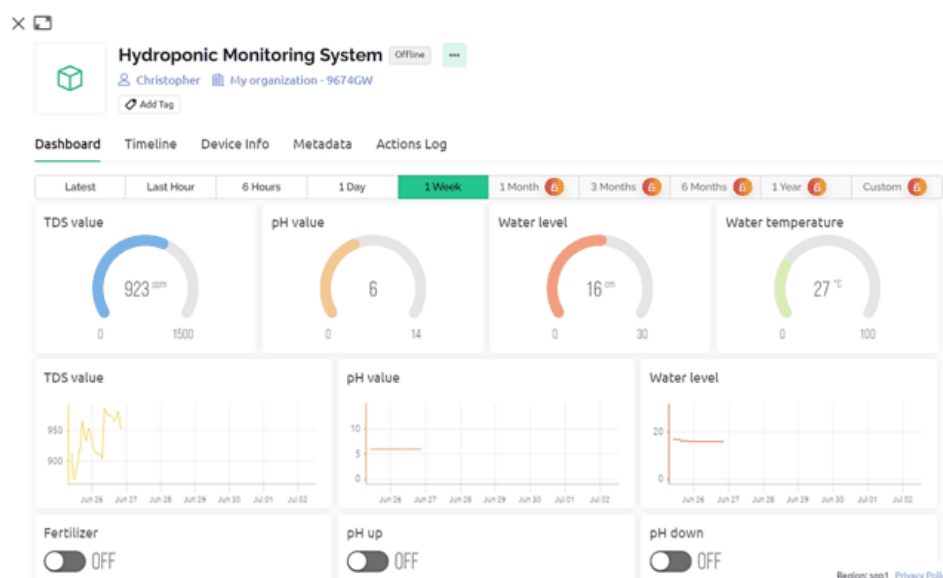


Figure 16: Web Dashboard of Blynk

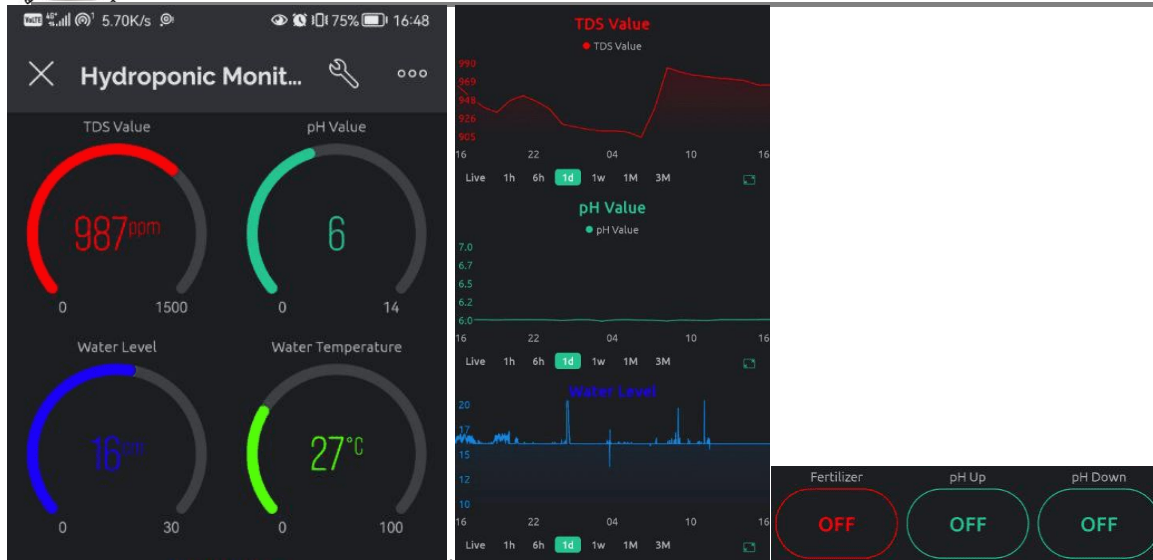


Figure 17: App interface of Blynk

Functionality of the IoT Application

The growth of the plants is based on the height(H), number of leaves(LN), fresh root weight(FRW) and fresh shoot weight(FWS) for each week of the growing time until harvest, where every parameters is averaged for four plants for each type of bok choy. The measurement is started after germination while the measurement of weight is done after the plants are harvest at the last week. H is measured by using a 30 cm standard scale as the length from the surface of hydroponic media to the highest free-standing point of the plant crown. LN is counted including leaves that were just beginning to unfold. After harvest, the roots are separated from the shoots by cutting the stem just above the hydroponic media. Both of the FRW and FWS are weighed using electronic balance.

Table 4: Measurement of Curly Dwarf Bok Choy

Week	H(cm)	LN	FRW(g)	FWS(g)
1	2.4	3	-	-
2	3.6	6	-	-
3	5.2	9	-	-
4	7.2	11	-	-
5	8.1	15	12	70.3
Total Fresh Weight(g):			82.3	

Table 4: Measurement of Shanghai Dwarf Bok Choy

Week	H(cm)	LN	FRW(g)	FWS(g)
1	2.5	3	-	-
2	4.1	7	-	-
3	5.9	9	-	-

4	7.6	12	-	-
5	8.5	16	15	76.2
Total Fresh Weight(g):			91.2	

From the result of the growth of plant, the mean total fresh weight of Curly Dwarf Bok Choy is 82.3g while the mean total fresh weight of Shanghai Dwarf Bok Choy is 91.2g. The yield is considered very good if compared to the result from [10], with the same vegetable cultivated which is Curly Dwarf Bok Choy with fresh weight of 82.1g/plant using raft hydroponic system (RHS). Also, with the density of 118 plants/m², the hydroponic system will yield 10.28kg/m², higher than the 5.1kg/m² from the RHS.

CONCLUSION

Based on the developed NFT hydroponic system and its functionality test, a conclusion can be made that the objective of this project are achieved. An automated hydroponic system has been developed successfully with complete software and hardware. the development of an automated hydroponic system which incorporates sensors to continuously monitor the crucial parameters that are important for hydroponic such as TDS value, pH value and water level of the nutrient water that circulates continuously in the system. This real-time data is collected and saved in the MicroSD card by the system and adjusts environmental conditions by nutrient dosages and pH control to maintain an ideal growth environment for plants. Additionally, the automated hydroponic system incorporates remote monitoring and control capabilities through the implementation of IoT application using Blynk, allowing user to monitor and manage their hydroponic operations from anywhere using mobile application or web interface. This automated hydroponic system also shows significant advantages over manual control of hydroponic since yield is increase with 10.28kg/m² where the weight per plant is from 82.3g to 91.2g.

ACKNOWLEDGMENTS

The authors thank Universiti Teknologi Malaysia and the project supervisor for the facilities, technical guidance, and constructive feedback that supported this study.

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