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An IoT-Based Hydroponic Monitoring and Control System for Sustainable Food Production

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Abstract: In recent years, declining soil fertility and unsustainable farming practices have led to pressing challenges for the agricultural sector. This has historically been the primary food source for the world. Meeting the escalating food demand economically necessitates intensified growing practices. To cultivate food and arable crops sustainably, this study introduces a type of smart farming which emphasizes the interconnectedness of food and water resources. A farming technique called hydroponics, which involves growing plants in nutrient water solutions, aligns with the food-water nexus by creating a controlled environment independent of soil. The development of a hydroponic system that monitors the temperature, humidity, pH, water, and light levels of the plants is essential to optimal growth and productivity. Nutrients are released as needed, thus preventing water waste. Finally, the system will provide real-time feedback on the environmental parameters. Leveraging Internet of Things (IoT) technologies, real-time data transmission from these sensors to Amazon Web Services (AWS) and an Android mobile app powered by a Raspberry Pi3 facilitates remote monitoring and control, automating the system and minimizing human intervention. Experimentation validated sensor network accuracy. The findings underscore the potential for widespread adoption of hydroponic farming to enhance global food security while addressing water use in agriculture. Future advancements might involve incorporating additional sensors, like carbon dioxide (CO2) sensors, for real-time plant growth monitoring. The integration of IoT with sensors has revolutionized hydroponic food production through precise and automated environmental monitoring. The resulting technological synergy, which combines real-time data collection, analysis, and automated adjustments, maximizes yields, accelerates plant growth cycles, and enhances agricultural quality. This research represents a pivotal step towards sustainable agriculture, within the food-water nexus system. Offering a technology-driven approach that will transform food production methods and ensure a more reliable and sustainable global food supply in the future.

Keywords: *Food-water nexus, global food security, hydroponics, IoT, sensors, smart farming, sustainable agriculture.*

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I.0 Introduction

Agriculture is essential for sustainable livelihood development [1]. Without well-practiced agriculture, which is the key source of healthy food production, living a good life may be a mirage [2]. There are two (2) known basic techniques to grow plants. It is imperative to critically investigate these techniques and propose the more sustainable, affordable, and reliable one for adoption [3]. When practicing commercial farming, the traditional method adopted globally is the use of soil to carry out farming which is currently being overburdened because of planting seasons which come periodically. Consequently, farmlands have lost their nutrients, and food security has constantly been threatened [4], [5][6]. Recent years have seen the use of smart farming to innovate crop production and enhance crop quality[7] [8]. Given the previous, the adoption of alternative, smart farming techniques known as Hydroponics [9] is necessary. In this method, farmers use nutrient solvents to grow plants instead of farming by the traditional way of using soil [10]. According to the literature, hydroponics is based on applying Information and Communication Technology in agriculture [9]. It is a system that is gradually taking up space in agricultural practice. The system uses water nutrient solution without the use of soil that is sometimes over-polluted or contaminated with chemicals coming from different industries such as manufacturing, agriculture, pharmaceutical and oil and gas [11]. Smart farming techniques, such as hydroponics, allow key parameters to be adjusted for optimal plant growth. A variety of factors are taken into consideration, including precise control of the nutrient solution, water recirculation, environmental factors like temperature, humidity, and light, continuous monitoring of pH and nutrients, sensor-based growth monitoring, and automated yield optimization. By implementing smart farming methods, resources can be utilized more efficiently, precise control can be achieved, and crop yields can be increased. Crop yields can be increased.

An IoT network connects computers, machinery, objects, living beings, and individuals. With their unique IDs, these devices exchange data autonomously with each other and computers without any human or computer intervention. The systems are connected via the internet and have sensors, tools, and online networks that allow them to evaluate and control themselves automatically [12]. Internet of Things (IoT) is reshaping industries, integrating internet connectivity with everyday items, transforming work, lifestyle, and technology[13]. In addition to reshaping industries, automation faces challenges such as high costs and intricate maintenance, which IoT might solve.[14]

The hydroponic farming technique has been the subject of several research studies using various methodologies to achieve successful results. Notable among them is the work in cited Ref. [15], by utilizing a microcontroller, the hydroponics control system developed regulates nutrients and monitors air and water temperature, as well as water levels. A mobile app collects sensor data, and a wireless sensor network transmits it to a central computer. In a related study in cited Ref.[16], the scholars studied a Nutrient Film Technique (NFT) hydroponic system for lettuce propagation using different wireless sensors. According to the study, the sensors measuring pH and electrical conductivity, which directly affect plant growth and nutrient uptake, had an error of 0.4 ms/cm and 5.1 ms/cm, respectively. The work in cited Ref. [17] used an Arduino UNO R3 board to automate nutrient feeding for a scaled-down NFT hydroponics setup. By integrating a servomotor with a faucet, it detects low levels of water and nutrient solution conductivity. The system automatically delivers water and adds nutrients when the water level falls below 800 ppm. The research in cited Ref. [18] developed a state-of-the-art IoT system called the Hydroponics Management System (HMS) to provide remote irrigation, pH, humidity, temperature, and water level monitoring. Urban residents can cultivate and manage their food more easily this way. The cited work in Ref. [19] explores a hydroponic gardening system using an IoT-based application tool. The author describes it as an affordable, adaptable system suitable for hydroponics. Its flexibility allows users to personalize their setup for their desired output, even without prior knowledge of the system. Authors in cited Ref. [20] developed an affordable DIY sensor-based mobile app for

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hydroponics. This indoor system is designed for small to medium-scale farming, particularly in subsistence farming. It includes temperature, humidity, and light sensors for managing and controlling the process. The authors in the cited Ref. [21] described a technique combining traditional farming with a nutrient-controlled, web-monitored hydroponic system. The prototype included sensors, cloud-based data analysis, and LED indicators for water levels, making it possible to cultivate hydroponic plants in small spaces at home. LED indicators confirm the system works effectively. The proposed work is to design a system that monitors and controls remotely some environmental parameters of a hydroponic smart farming system. This is to improve food security. Through an Android mobile application and the cloud service offered by Amazon Web Services (AWS), this automation made possible by IoT technology will ensure that users can monitor and control various environmental parameters. Among these measures are regulating water levels in the growth medium, managing temperature and humidity, pH levels, and regulating light usage to facilitate uninterrupted photosynthesis. The proposed system offers several contributions to knowledge: Sensor integration within the system enables data-driven decision-making. Secondly, through the incorporation of automation and control elements, the system empowers clients to monitor and adjust environmental parameters remotely. Additionally, the hydroponic system is evaluated by analyzing extensive sensor data using Amazon Web Services.

The rest of the paper is sectioned as follows: Section II describes the design requirements and specifications; Section III describes the proposed system in detail. The paper concludes with Section IV which gives step by step experimental situations with results and concludes with future work.

II Design Requirements and Specifications

The proposed hydroponic system integrates essential hardware and software components alongside intelligent sensors to monitor pH, light intensity, nutrient solution, and humidity levels. Specific criteria outlined in tables and schematics guide the selection of these sensors, with each sensor playing a critical role in enhancing the system's performance and functionality. The tables specify individual details of sensors such as the DHT11 Temperature and Humidity Sensor [11], Analog pH meter Sensor [12], Total Dissolved Solid (TDS) Sensor [13], and Ambient Light Intensity Sensor [14]. A Raspberry Pi 3 Micro-controller manages these vital components, while a Water Pump circulates the nutrient solution. Detailed hardware specifications appear in Tables 1 through 6.

Table 1. Specifications of the DHT11 Temperature and Humidity Sensor

Temperature and Humidity Sensor	**Model: DHT11**
Operating Voltage	3.5V to 5.5V
Connection Protocol	One wire
Output	Serial data
Temperature Range	0°C to 50°C
Humidity Range	20% to 90%

The temperature and humidity sensor specification are shown in Table 1. This sensor is highly sensitive with tolerance value of plus or minus one percent (±1%).

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Table 2. Specifications of the Analog pH meter Sensor

Analog PH Sensor	**Model: SEN1061**
Module Voltage	5V
Measuring Range	1-14PH
Accuracy	±0.1PH (25^{0}C
Connection Protocol	Three (3) Wires

Shown in Table 2 is the specification of analog PH sensor with a level of stream accuracy of 0.5PH

Table 3. Specification of the Total Dissolved Sensor (TDS)

TDS sensor	**Model: DF Robot SEN0244**
Input Voltage	3.3V to 5.5V
Output Voltage	0-2.3V @3-6Ma
Measurement Range	0-1000ppm
Accuracy	±10% @ 25°C
Connection Protocol	Two wires
Module Interface	PH 2-3P

For the measurement of dissolved solid solution nutrient level, a sensor called Total Dissolved Sensor is used. It indicates how many milligrams of solids have been dissolved in one liter of water. The sensor's specification as employed in the design is shown in Table 3

Table 4. Specifications of the Ambient Light sensor

Ambient Light Intensity Sensor	**Model: Adafruit VEML77**
Operating Voltage	3-3.6V
Digital Output	16 Bit 12C fast mode at 400kHz
Lighting Ripple Reaction	50/60Hz
Pin	Programmable Interrupt pin and function
Resistors	12C pull-up

To measure light intensity within the house, the ambient light intensity is used. Table 4 is the specification of the ambient light intensity sensor as deployed in the system's design.

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Table 5. Specifications of the Raspberry Microcontroller unit (MCU)

Raspberry pi 3	**Model: Pi 3**
Input Voltage	5V via USB and 5V DC via GPIO header
Operating temperature	0-50°C
Compliance	ICASA Approved
Memory	4GB
Processor	Broadcom BCM2711, quad-core cortex A72
GPIO	Standard 40pin GPIO header

The microcontroller is the heart of the entire system as it coordinates the activities of all the sensors and other devices operating within the system. Its specification is shown in Table 5. The type of Microcontroller as indicated in the Table is Raspberry Pi3 having high speed and large memory.

Table 6. Specifications of the water pump

Water Pump	**Model: water pump f700**
Power	10W
Flow Rate	700 Lit,/hr
Wiring protocol	3 core/10m long electrical cable

The specification of the water pump deployed solely for the purpose of pumping water and nutrients solution to the growing tray of the plants is shown in Table 6.

The following assumptions guided this study:

- The control system shall act independently and shall not affect the environment.
- The components used in the hydroponics system shall not conflict with the environment.
- The components shall be environmentally friendly and will not contain any toxins that shall harm the environment in any manner.

III Hydroponics System Design

System design and implementation follow the proposed subsystems in Fig. 1. As shown in the subsystems configuration, the physical system relates to the data collection sub-system, and the control system uses the data

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to execute decisions based on past and present data. Sub-systems operate independently, but when they are all connected, they form one hydroponic system.

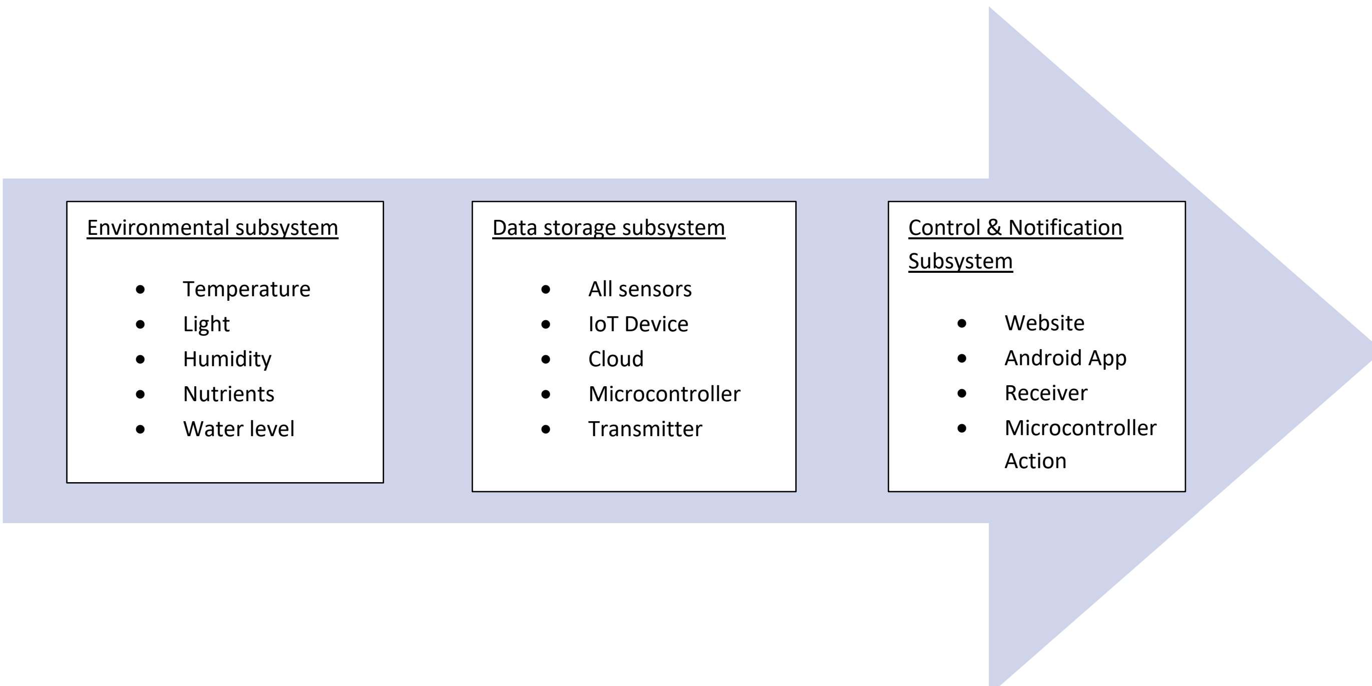

Fig. 1. Subsystems configuration of the hydroponic system.

Given the requirement of monitoring the temperature, humidity and other sensors of the hydroponics system, high level functionalities and performances are expected of the system when fully implemented.

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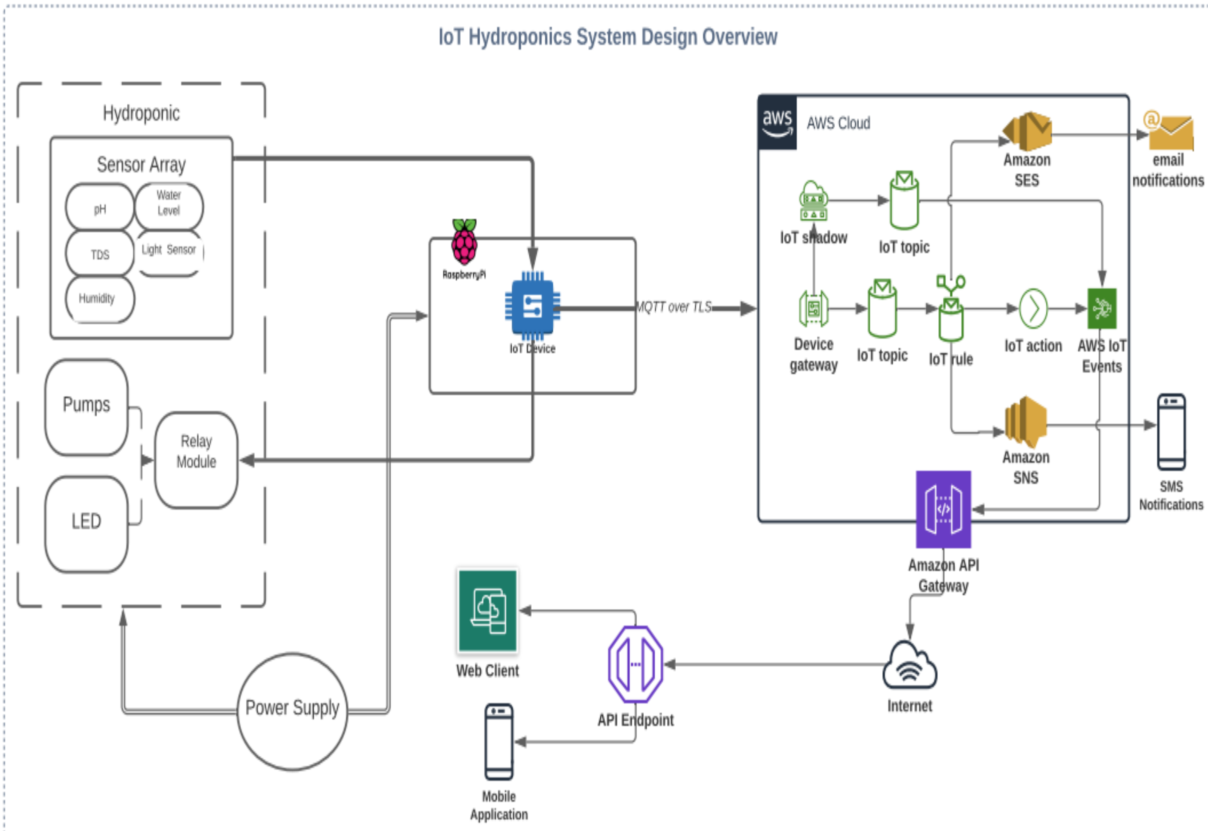

Fig. 2. The design concept of hydroponics system

There are multiple advantages to the chosen hydroponics design, including but not limited to:

- Cost-effectiveness
- Simple construction
- Easy-to-use and learn Amazon Web Services deployment.
- The absence of a timer eliminates the need for a dedicated power supply.
- Simple cloud connectivity through IoT using the Raspberry Pi 3 microcontroller.

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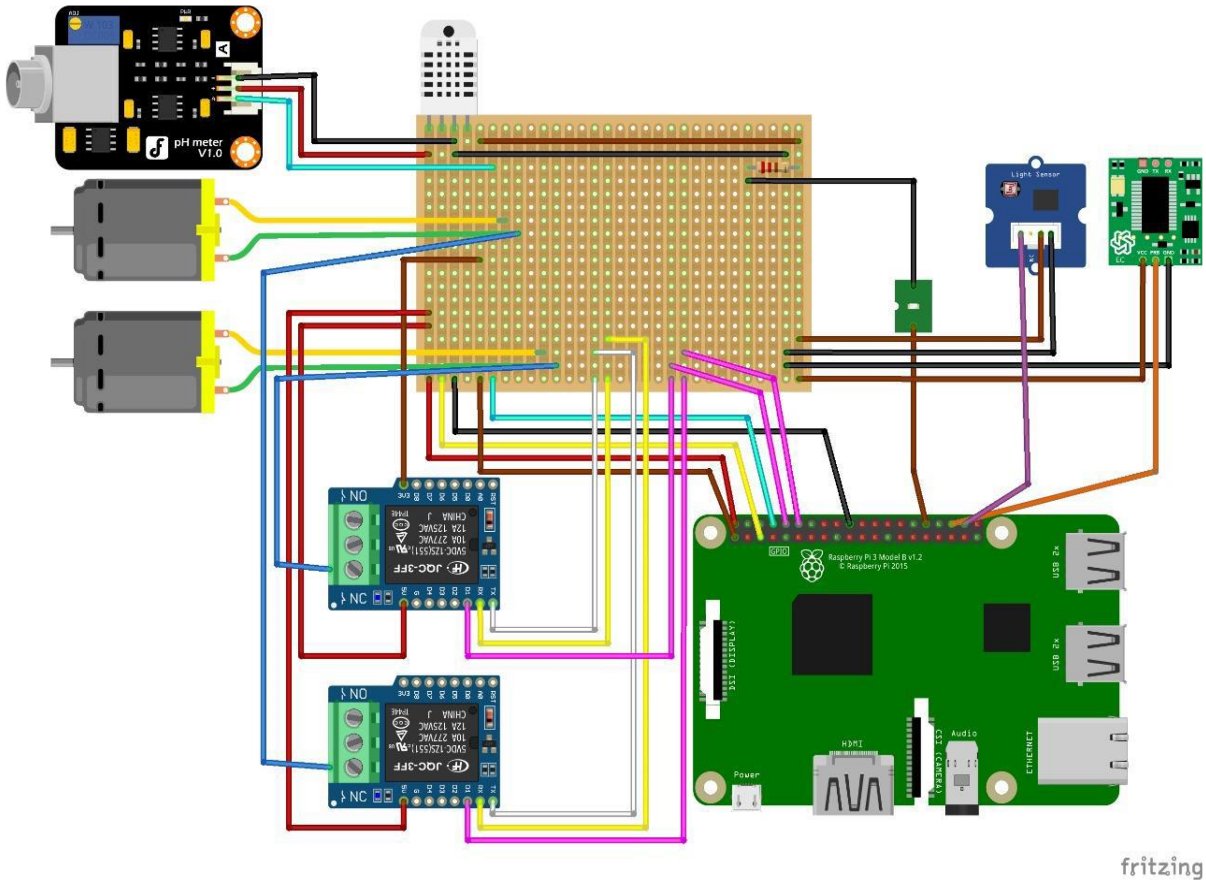

Fig. 3. System design schematic

Fig. 3 depicts the schematic diagram of the proposed hydroponics system drawn using Fritzing application.

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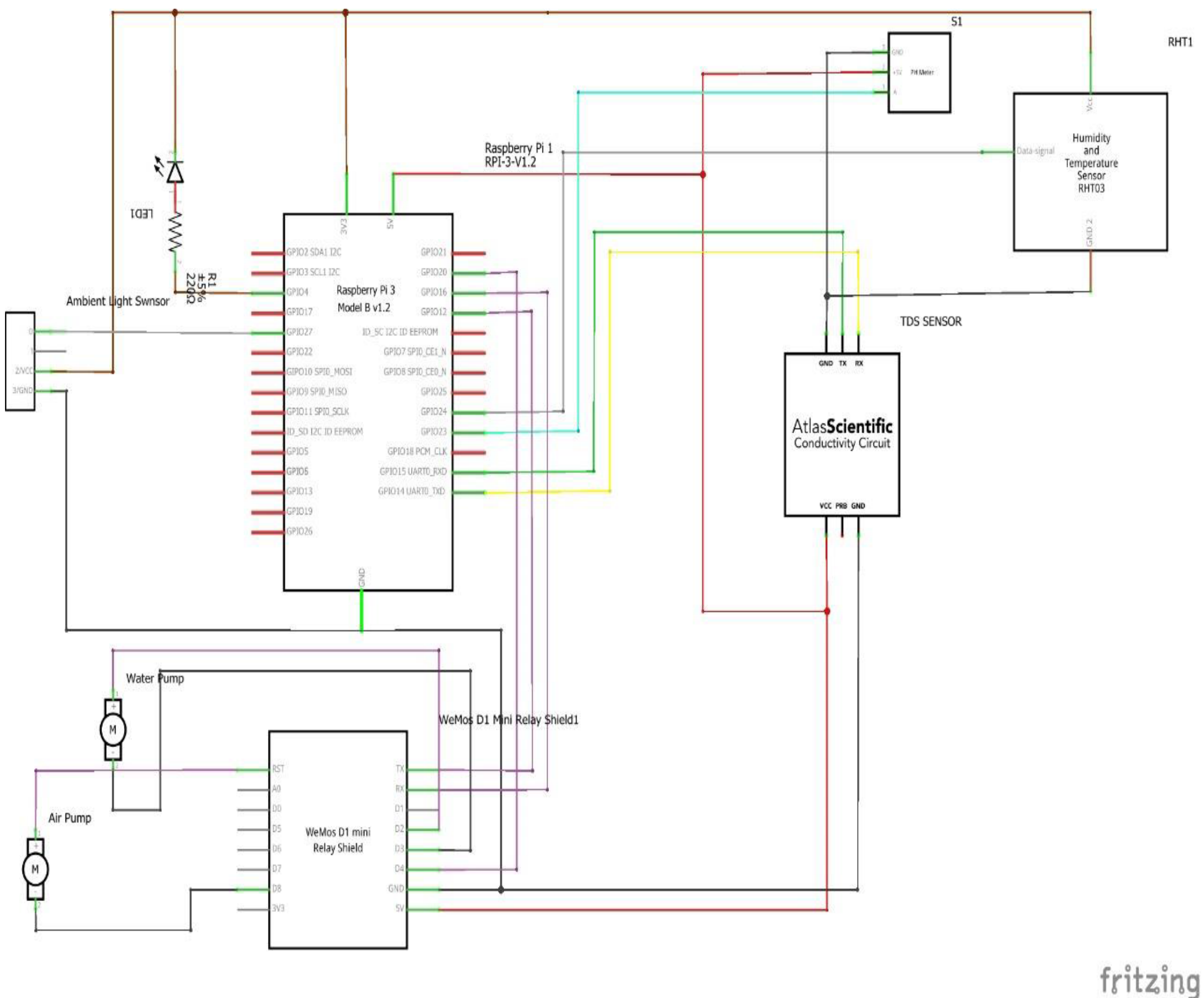

Fig. 4. Equivalent Circuit Diagram of the Hydroponics System

Both the schematic diagram and equivalent circuit diagram have been produced based on the system design requirements and specifications as shown in Tables 1 – Table 6.

IV Laboratory Experiments and Results

The step-by-step experimental situations as conducted in the lab to establish the compliance of each sensor with the specification as stated in section II of this research is elaborately discussed in this section. Each sensor was subjected to laboratory test one after the other according to the established rules and norms for testing sensors.

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i. Water level Test

The system was designed to have its valve closed when the water level reaches a set threshold; in the same vein, the water level sensor indicates that water has been detected at a stipulated level. The setup of the experiment is shown in Fig. 5.

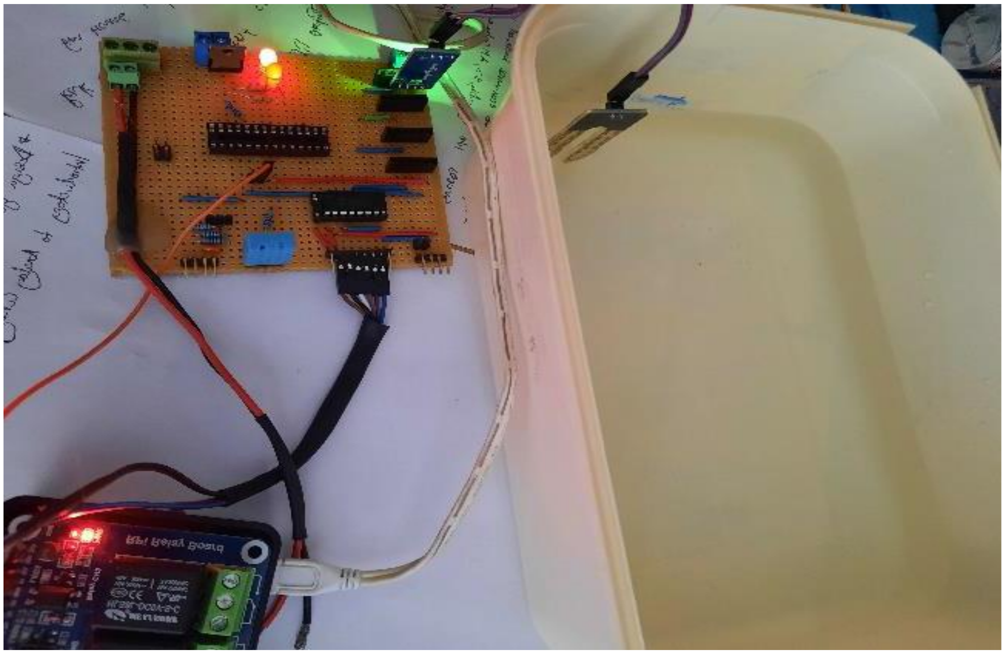

Fig. 5. Water level Sensor setup

- Results

The measurements results generated by the water level sensor are displayed as evident in Fig. 6 to indicate the water level. The water level height was also measured to show the water level measurement at each height.

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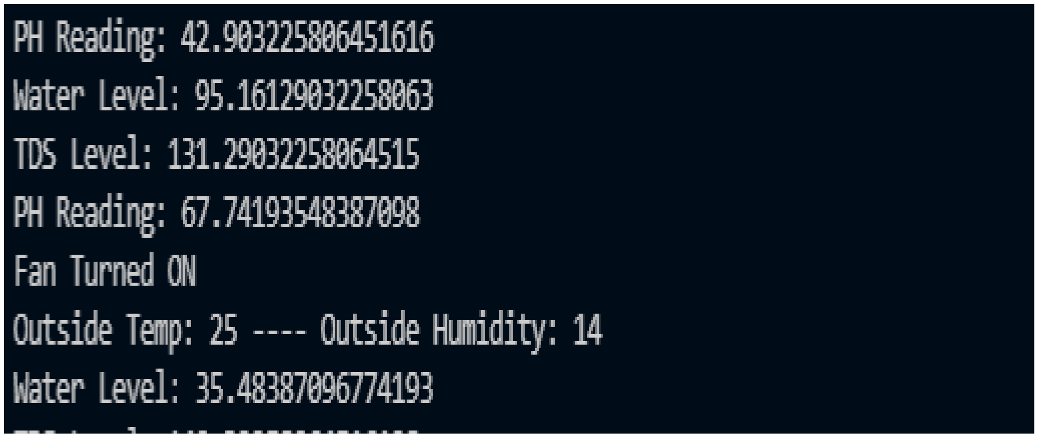

Fig. 6. Terminal window for the display of the results of water level sensor.

It is imperative to show in tabular form, the relationship between the water level height and the water level sensor reading; this is shown in Table 7.

Table 7. Water level and sensor data

Water Level (mm)	Sensor Readings
No water (0 mm)	255
20mm	130
30mm	100
40mm	80
50mm	70
>55mm	50

- Analysis

The sensor readings displayed a number on the meter of 0-255, 255 indicates that, there was no water detected by the sensor at that time. As the water level began to increase as detected by the sensor, the value also began to decrease indicating the amount of water that had been detected. Since the application of the water level sensor was to determine when the water level had reached a certain level, it was sufficient to use the water level sensor in this regard. From the results

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obtained from the experiment conducted and the test repeated for consistency, the water level could be obtained by mapping the 0-255 range to the height of the sensor which was sufficient since at the given level any value below 130 would be considered as the water being present at that height.

ii. DHT11 Temperature and Humidity Sensor Test

The DHT11 sensor set up was configure onto the main system as shown in Fig. 5, The Sensor values were taken on for 5 days at 3-hour step intervals and were compared to the readings that were obtained from the weather bit for the same period. [15]

- Results

The plot in Fig. 7 shows the temperature results from the DHT11 sensor and compared with the weather station temperature to establish the accuracy of the DHT11 sensor.

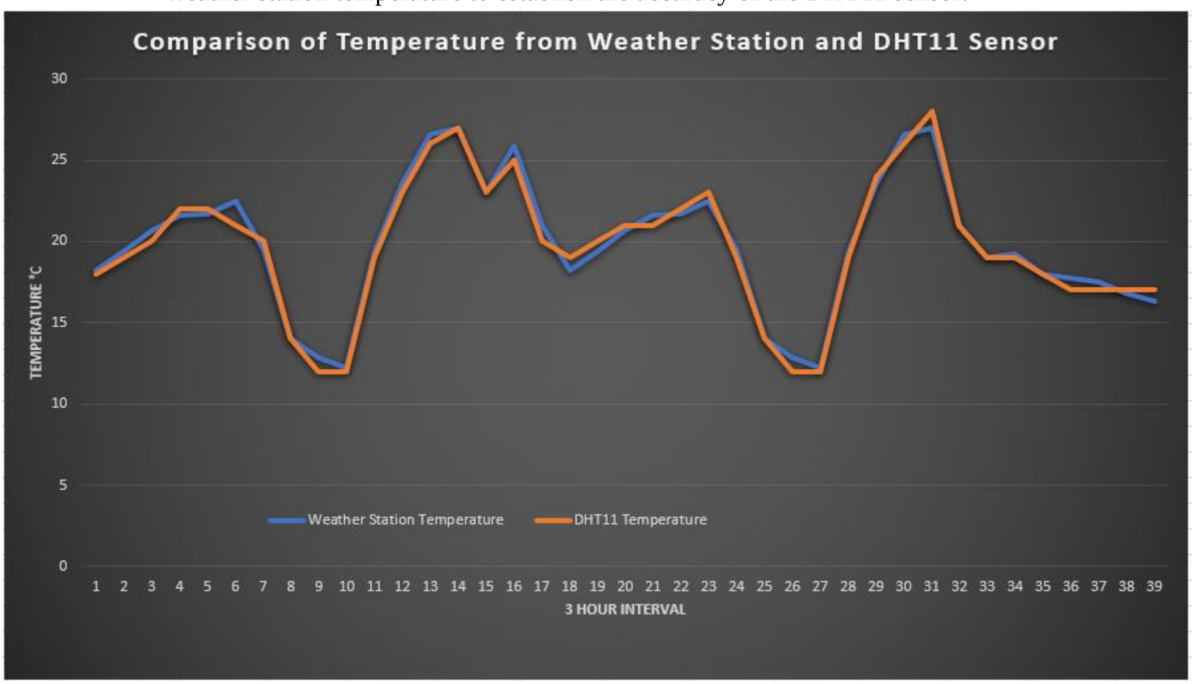

Fig. 7. Comparison of weather station temperature with DHT11 sensor temperature

The plot in Fig. 8 shows the humidity results from the DHT11 sensor and compared with the weather station humidity to establish the accuracy of the DHT11 sensor.

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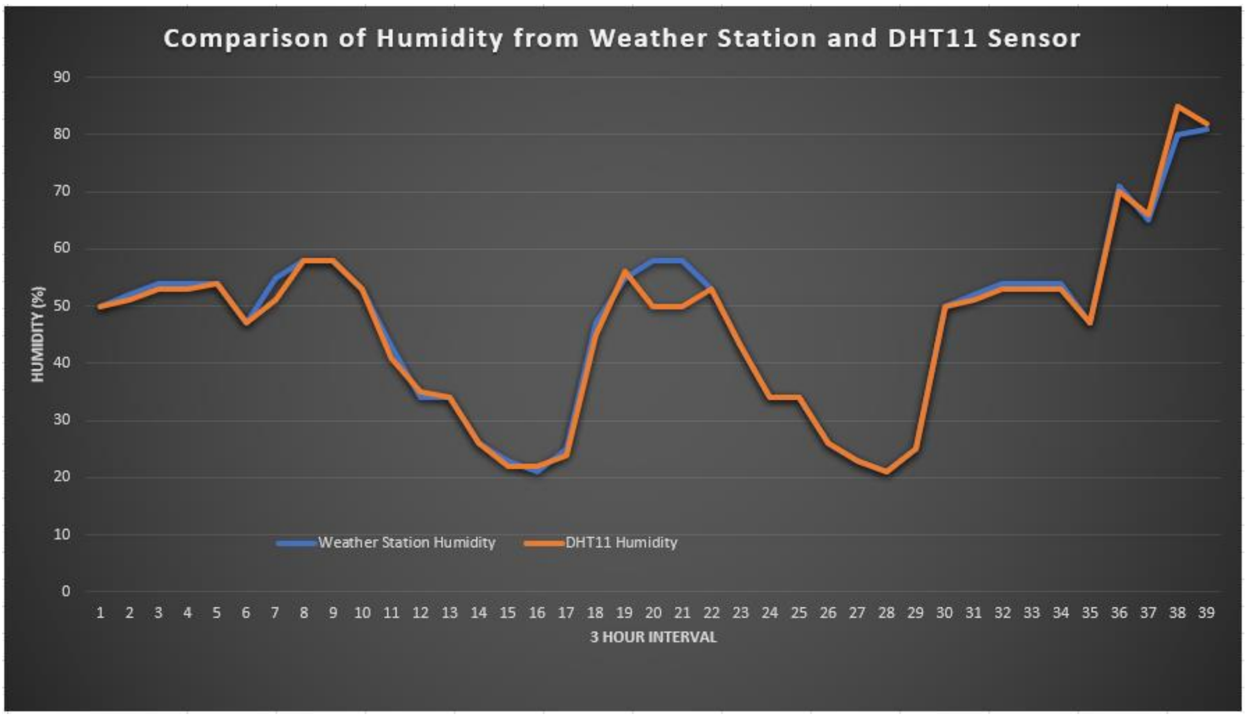

Fig. 8. Comparison of weather station humidity with DHT11 sensor humidity

To further establish the accuracy of DHT11 sensor, the temperature and humidity data generated by DHT11 was compared with the data generated by the Johannesburg CITY weather station[22] using ANOVA analysis as shown in Tables 8 and 9 respectively.

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Table 8. ANOVA analysis comparing DHT11 sensor temperature data with weather station temperature data.

Temperature Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Weather Station	39	774.15	19.85	16.36127		
DHT11 Temp Sensor	39	768	19.69231	16.95547		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.484904	1	0.484904	0.029109	0.864982	3.96676
Within Groups	1266.036	76	16.65837			
Total	1266.521	77				

Table 9. ANOVA analysis comparing DHT11 sensor humidity data with weather station temperature data.

Humidity Anova: Single Factor						
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Humidity from Weather Station	39	1826	46.82051	243.4669		
Humidity from DHT11 Sensor	39	1802	46.20513	245.9568		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	7.384615	1	7.384615	0.030177	0.862552	3.96676
Within Groups	18598.1	76	244.7119			
Total	18605.49	77				

- Analysis

Observing the plots shown in Fig. 6 and Fig. 7, it can be confirmed that when compared with weather station observations, the temperature and humidity values that are obtained for the same region are similar. To further the research, a hypothesis that the two sets of readings are similar was conducted and analysis of variance test was done on both datasets to see how similar the sets were. Also, for the test, the null hypothesis was carried out

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to establish that the sets are similar; the high p-value obtained gives high confidence that the null hypothesis is correct, and the value obtained is similar. The temperature readings had a p-value of 86.50% and the humidity readings had a p-value of 86.26%. This reference confirmation gives confidence that the DHT11 sensor was working as expected since it aligns with the weather bit results and the data provided to the system will therefore be accurate because of the high probability value.

iii. pH Sensor Test

Buffer solutions of known pH were used to provide a control setup for the pH test, other chemicals such as vinegar and distilled water were also used to ensure that the sensor was working and accurately responding to the pH levels as expected. Fig. 9 shows how the buffer solution was used to get the reading of the sensor at a neutral point. The buffer solution was known to be 7.00 as illustrated:

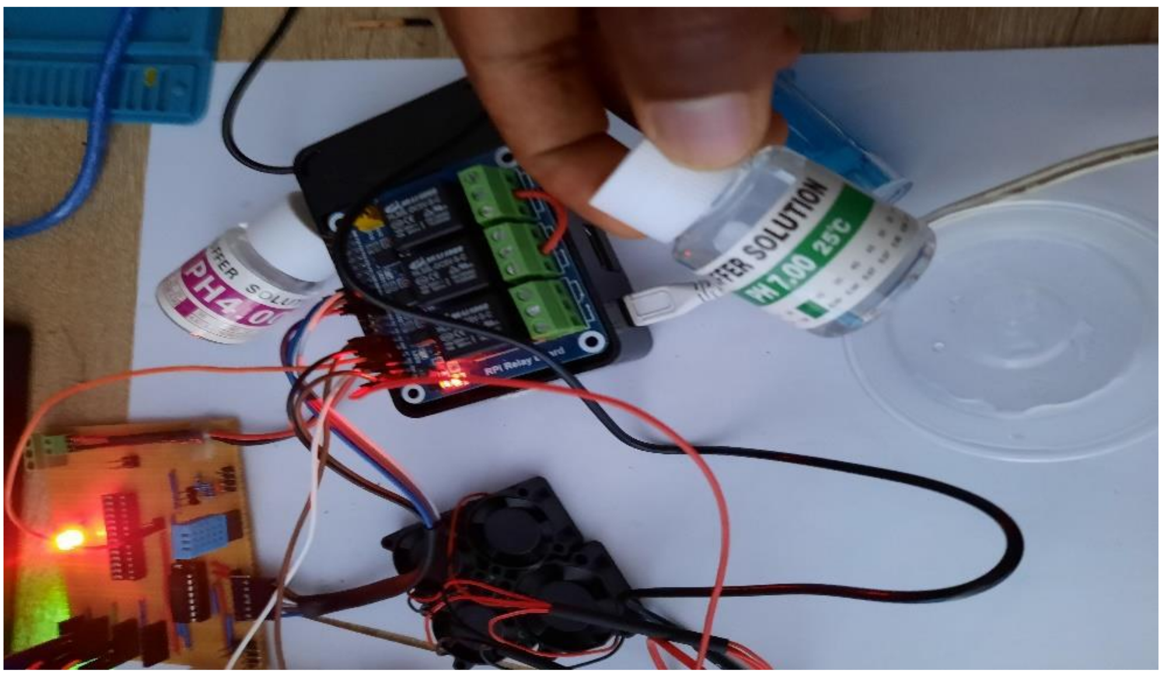

Fig. 9. pH sensor setup buffer solution of 7 pH.

The pH probe was inserted into the buffer solution and the sensor reading displayed on the terminal window and recorded.

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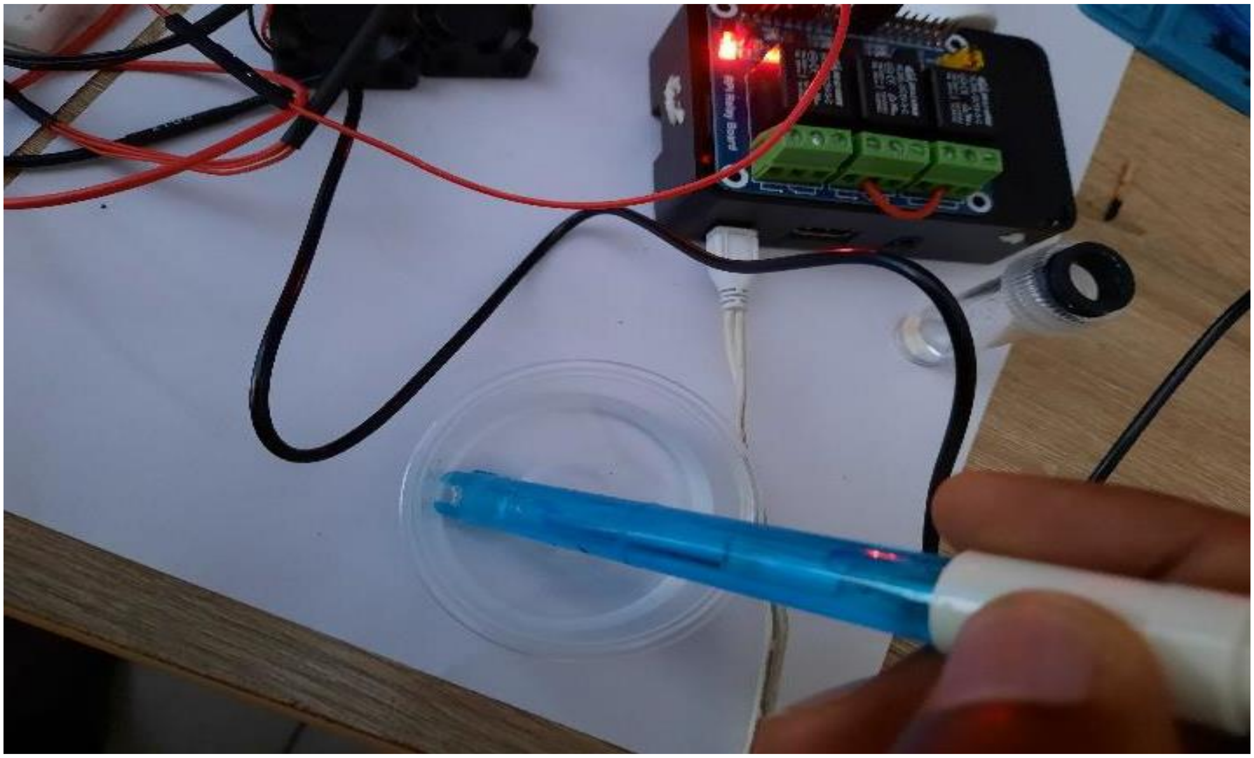

Fig. 10. pH sensor setup with testing probe

The second buffer solution that was used to record the pH recording off the sensor was calibrated at a pH level of 4.

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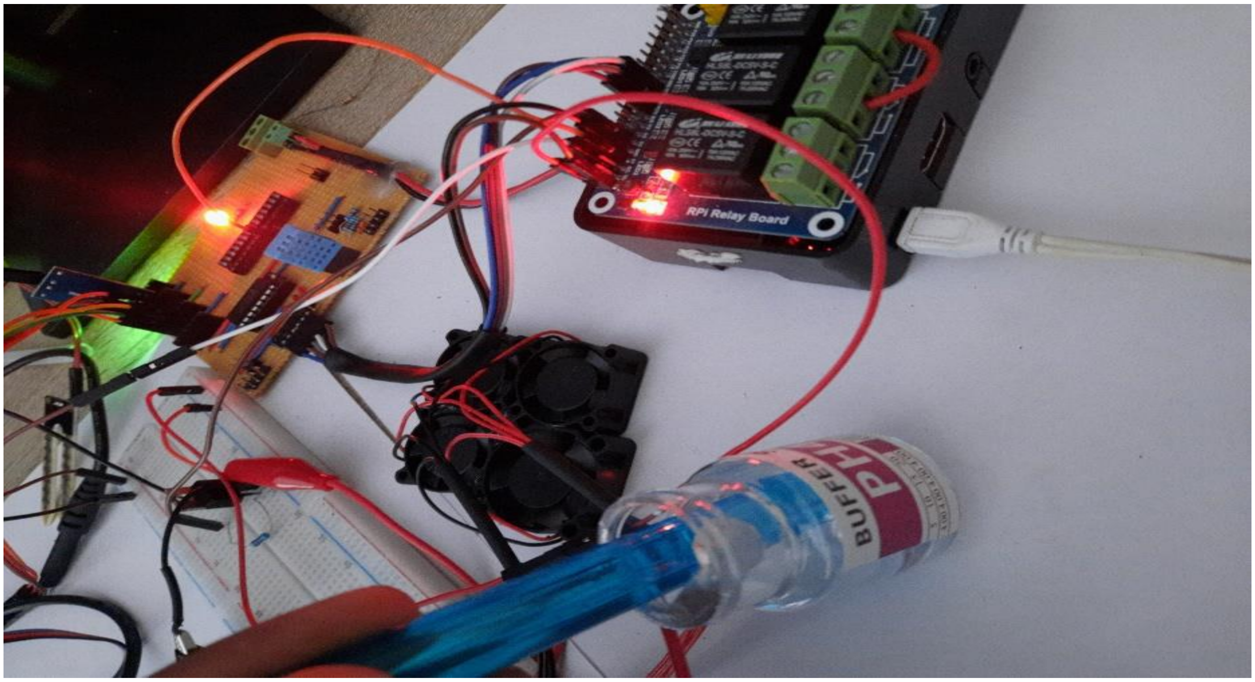

Fig. 11. pH sensor setup with a buffer solution of 4 pH.

- Results

The following results depicted in Table 10 were obtained from the pH sensor tests.

Table 10. Results for pH sensors tests

pH Values	pH Sensor Readings
White Vinegar (~2.5pH)	168
Buffer Solution A (4.00 pH)	292
Buffer Solution B (7.00 pH)	501
Oven Cleaner (~13.00 pH)	989

Fig. 12 shows the relationship between the pH sensor scale and the pH values obtained from the raspberry Pi.

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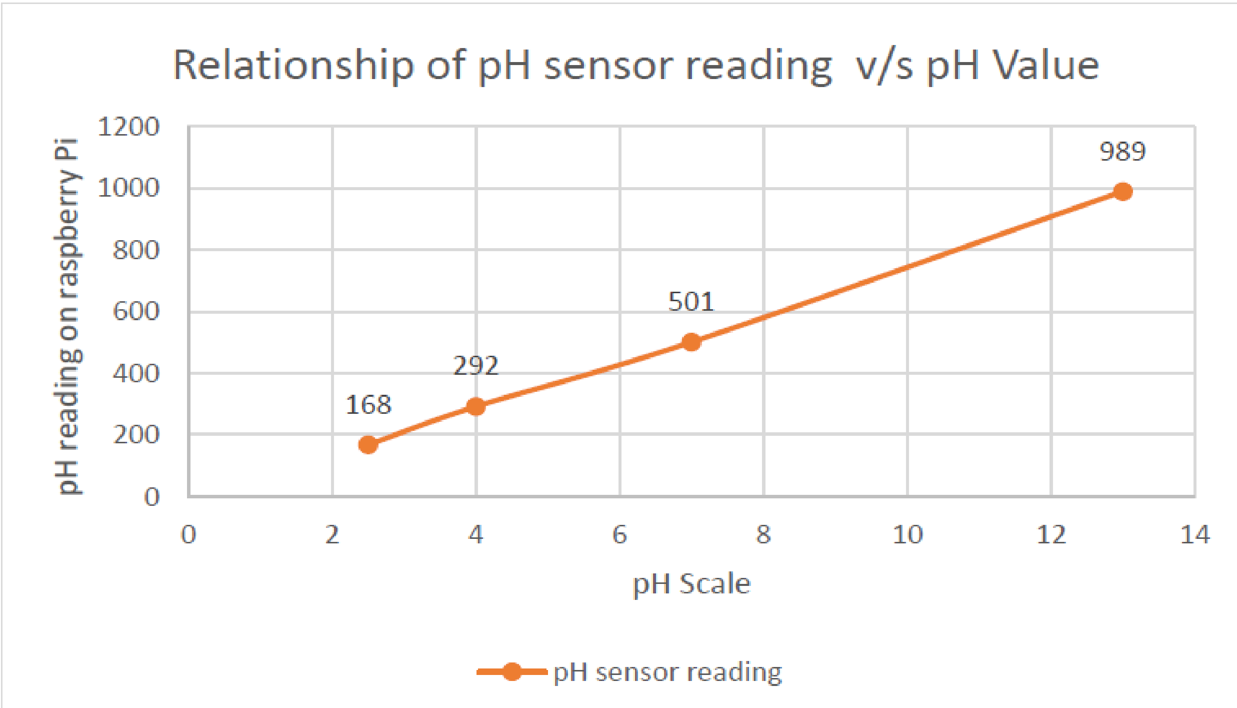

Fig. 12. Relationship between pH scale and obtained sensor readings.

- Analysis

Fig. 12 illustrates a linear relationship between sensor values and known pH values. The consistency of the relationship for the known pH values made it possible to conclude that the pH sensor was producing accurate and expected results as it has been deduced from the experiment.

iv. Total Dissolved Solids (TDS) sensor Test

Sodium Chloride was used to measure the amount of Total Dissolved Solids that were added to distilled water. The sensors were used to show the relationship of the dissolved sodium chloride to that of the TDS Sensor reading.

- Results

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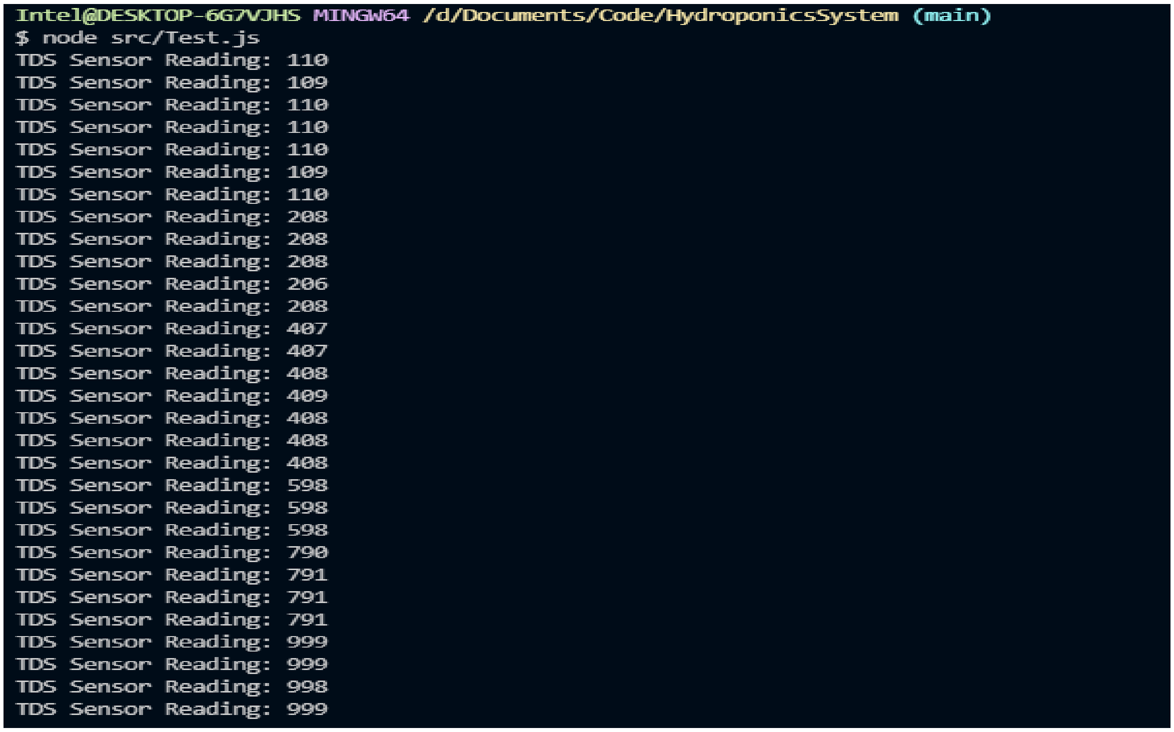

Fig. 13. Real-time TDS sensor readings taken every second during salt addition.

Table 11. Salt measurements and TDS sensor readings.

Salt Measurement	**TDS Sensor Reading**
0g/L (Distilled water)	0
0.1 g/L	110
0.2 g/L	208
0.4 g/L	408
0.6 g/L	598
0.8 g/L	791
1 g/L	999

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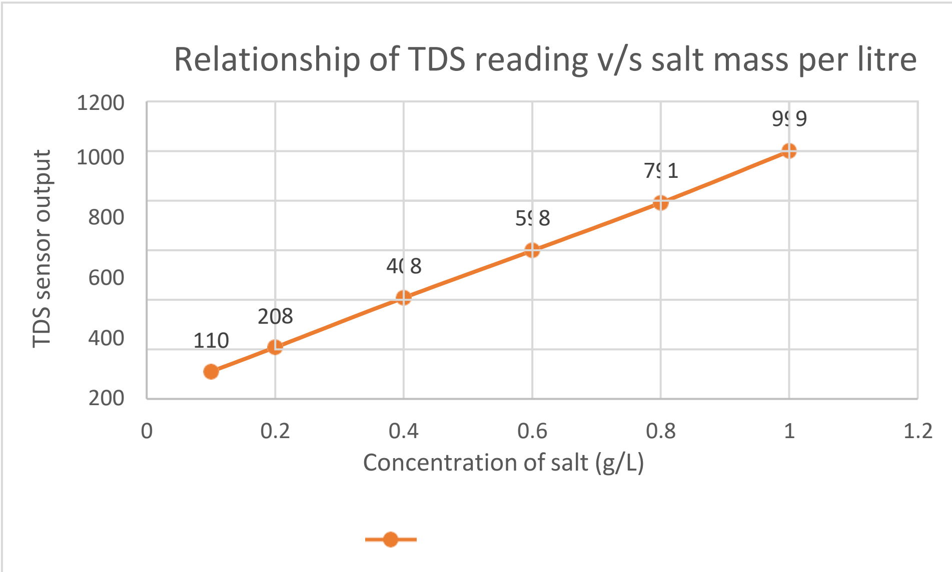

Fig. 14. Relationship of salt concentration in water and TDS sensor output.

- Analysis

The linear relationship between the salt concentration and the TDS sensor made it possible to deduce the amount dissolved of solids in the water. With the information, a threshold could be defined to allow the system to respond based on the obtained threshold. The perfect relationship obtained verified that the sensor was indeed and producing expected results.

AWS Services Integration

Water Level Sensor Readings

To verify that data was being successfully sent over to the cloud and consumed bythe AWS service successfully, the values that were read from the water level sensor were displayed on both terminal windows i.e. The raspberry pi's terminal and the AWS console.

- Results

The result in Fig. 15 shows the water level data sent to the AWS cloud using the WI-FI module connected to the raspberry pi.

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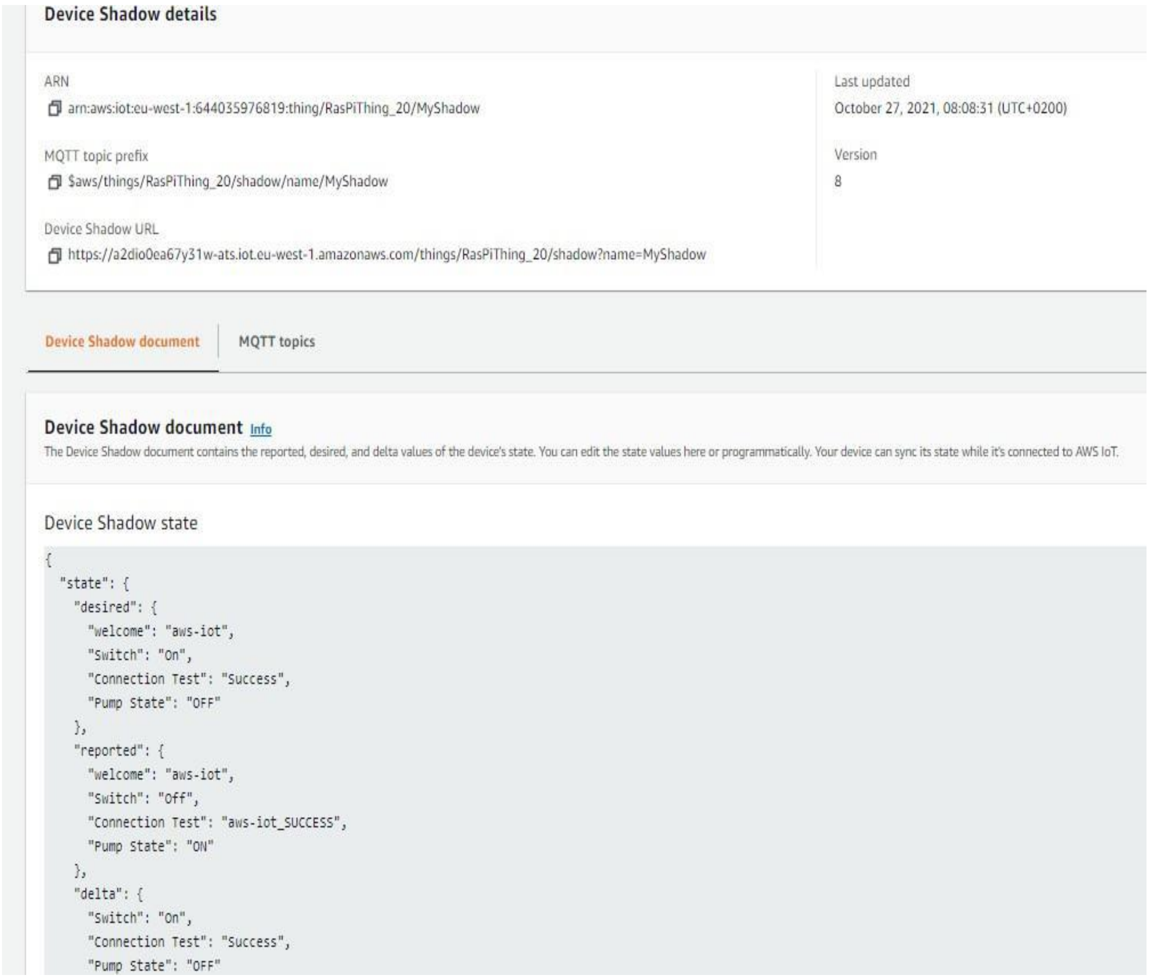

Fig. 15.AWS MQTT Connection verification.

Fig. 16 shows the sensor readings on the AWS cloud to show that the raspberry pi was able to send through the data readings to the cloud.

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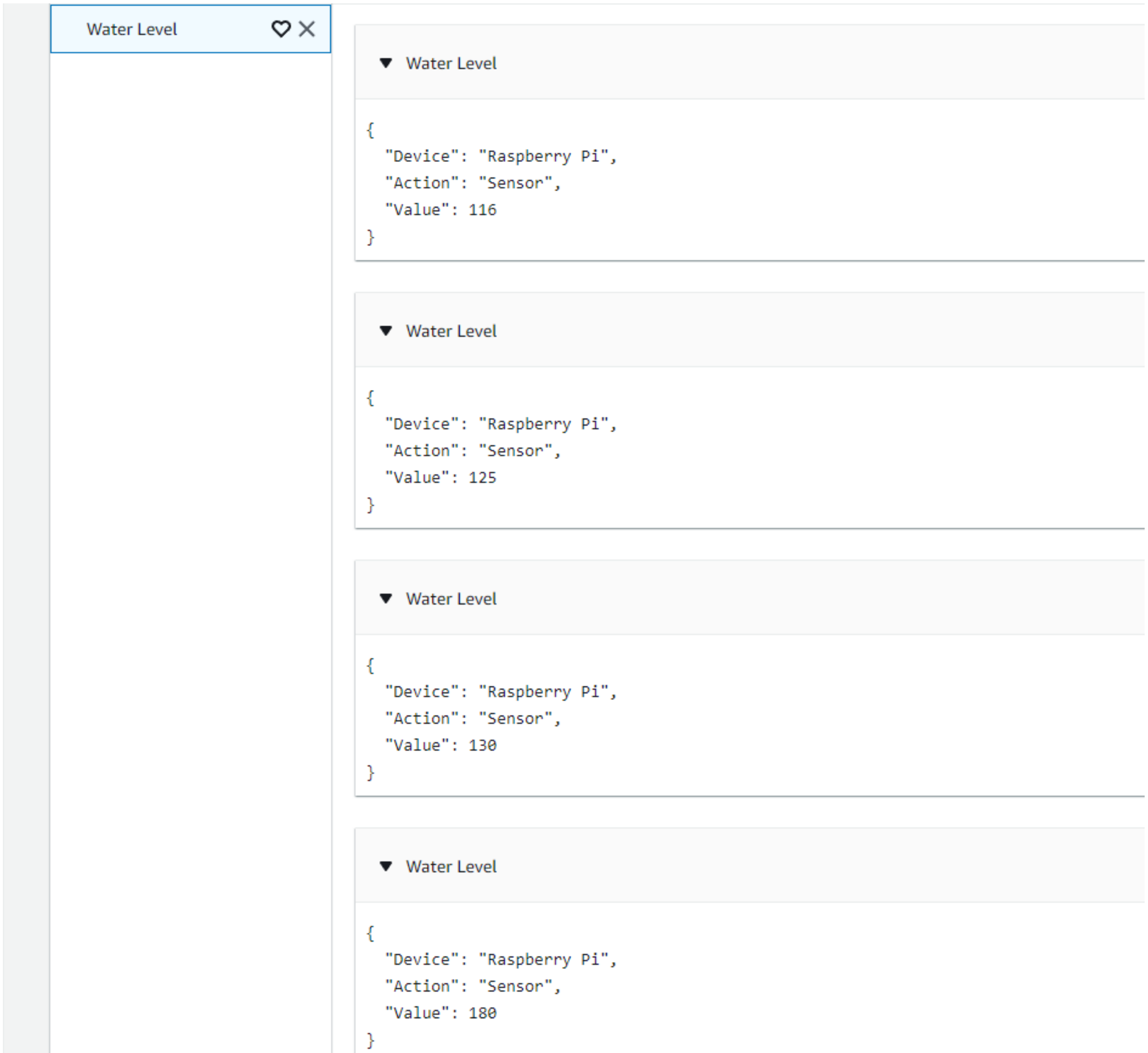

Fig. 16. AWS dashboard showing received sensor data.

- Analysis

The results obtained indicate that the sensor data was successfully pushed on the AWS servers and all the subscribing topics could get a copy of the sensor data. This allows many clients including the application interface to subscribe to the topics so they can get a copy of the data. The connection between AWS services and the raspberry pi was confirmed as the data from the sensor was published successfully.

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B. Notification and Control Test

- Water Valve Test

To guarantee that water flow is managed, a water flow valve must be capable of restricting and allowing water flow when specific criteria are satisfied. The water level (soil moisture) sensor was used to illustrate the functionality of the water valve to verify its operation and ensure that it was functioning properly.

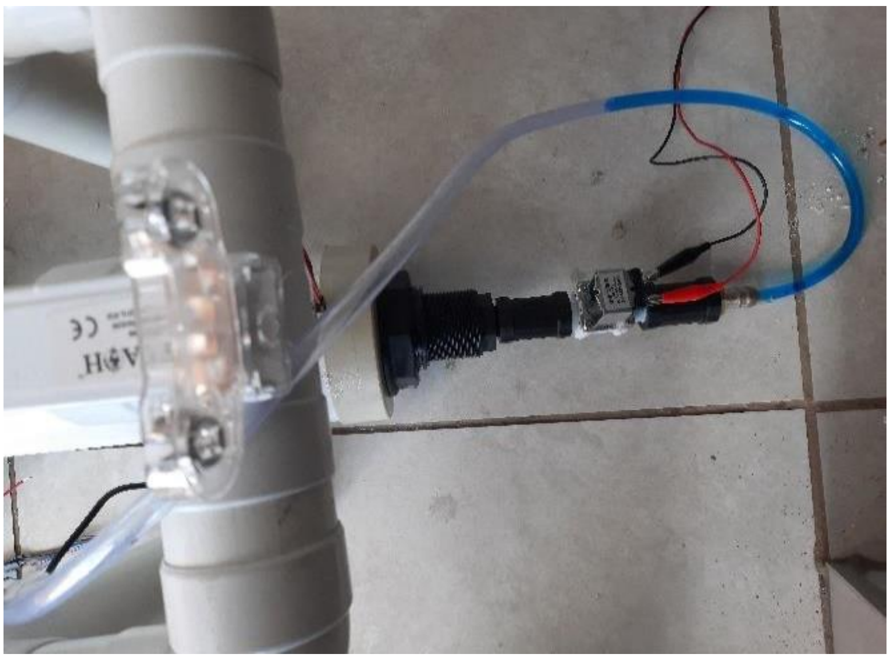

Fig. 17. Water valve setup.

Table 12 shows the water level sensor readings and the state of the water valve compared between the water valve's expected state and the water valve's observed state.

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Table 12. Water level sensor readings with the expected state of the water valve and observed state.

Water level Sensor Reading	Water valve expected state	Water valve observed state
255	ON	ON
240	ON	ON
225	ON	ON
200	ON	ON
195	ON	ON
175	ON	ON
160	ON	ON
145	ON	ON
130	ON	OFF
115	OFF	OFF
100	OFF	OFF
85	OFF	OFF
60	OFF	OFF
50	OFF	OFF

- Results

Water Pump Test

The water pump test was performed to demonstrate that water was pumped properly throughout the system. A colorant was used to indicate the water flow. Fig. 18 shows the water being pumped from the tub to the growing medium. The blue colorant is used as a test to show the visibility of this test since water is clear and it was not going to be clear if the water is indeed being pumped from the tub to the growing medium.

Fig. 18. Water flow setup

Fig. 19 shows the blue water being fully pumped.

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Fig. 19. Water flow stopped at the valve.

We compared the pump state and the expected water level state to ensure that the pump worked as expected. Table 13 illustrates how the water pump behaved at different levels.

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Table 13. Water level sensor readings with expected water valve state and observed state.

Water level sensor reading	**Water valve expected results**	**Water valve observed state**
255	ON	ON
245	ON	ON
220	ON	ON
205	ON	ON
190	ON	ON
170	ON	ON
165	ON	ON
140	ON	ON
135	ON	ON
110	ON	ON
105	OFF	OFF
85	OFF	OFF
60	OFF	OFF
50	OFF	OFF

- Analysis

So far, a good number of sensors mentioned in this research have been tested in the laboratory based on the requirements and their specifications to ascertain their workability and accuracy when compared with the existing devices. Other sensors were also tested using the same approach and they were found functional, and their performances followed standard rules.

Notification Test

The notification test was performed to demonstrate that a notification was received by the user when critical conditions and significant changes had occurred in the system.

- Results

Fig. 20 shows a test of the notification systems when temperature was at 4°C

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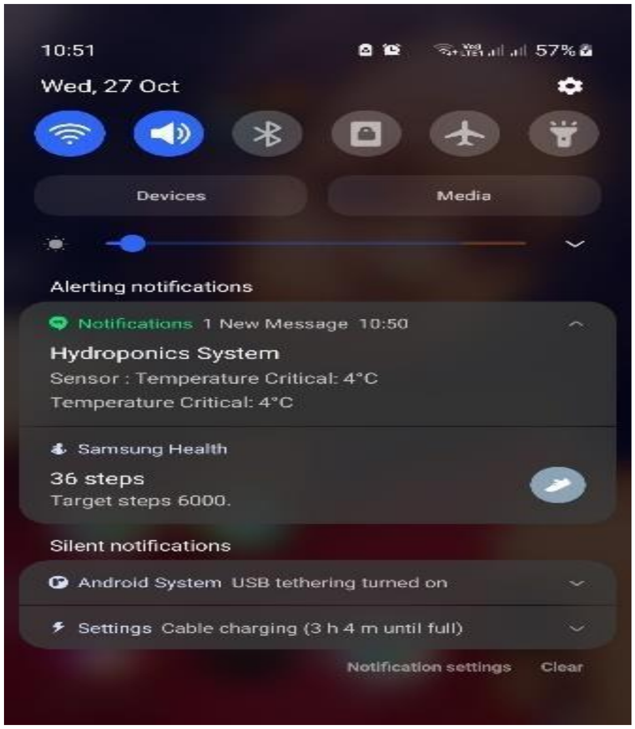

Fig. 20. Testing temperature notification display.

- Analysis

The notification received indicated that the system could deliver mobile notifications when an adverse effect has been detected, for this instance it was atthe temperature of 4°C.

Application Interface control test

This test was carried out to show if the system controls could be monitored accurately on the smartphone application and if the physical control devices weresynchronized on the app interface.

- Results

Fig. 21 shows the display of the temperature, humidity, water level, and the state of the pump.

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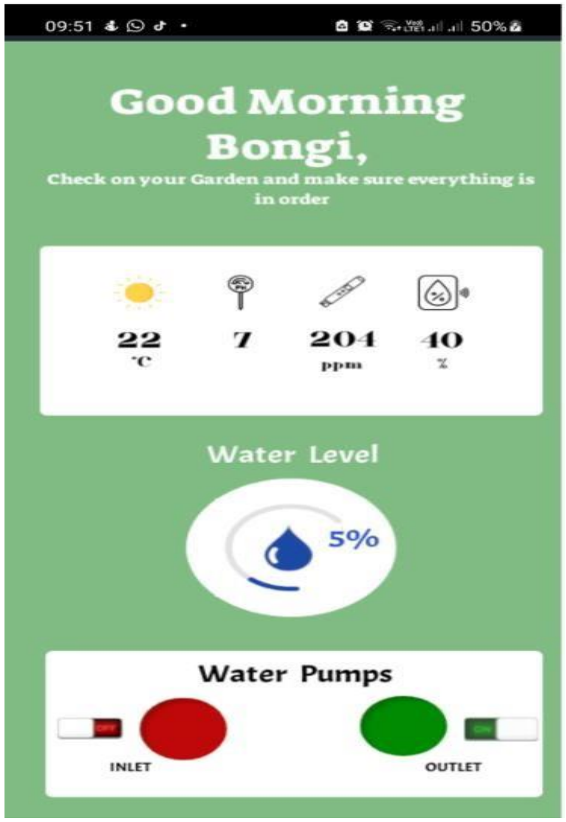

Fig. 21. Application interface to control system.

- Analysis

  The application successfully displayed the conditions of the system, and the pumpcontrol could be overridden by using the application control buttons. The application interface can also be used to monitor the environmental conditions and control the light of the system.

Integration system test (Control measures)

Pump control

To demonstrate that the pump was fully operational as a control measure, an integration test was conducted from detection using the data from the sensor tothe notification on the Android mobile application, a typical process was recorded, and results are given in Fig. 22.

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- Results

WATER LEVEL BELOW 22MM

The Fig. 22 shows the sensor readings detecting low water level height onthe water level sensor.

```
Current Water Level: 0mm
Water Pump: ON
Current Water Level: 1mm
Water Pump: ON
Current Water Level: 5mm
Water Pump: ON
Current Water Level: 7mm
Water Pump: ON
Current Water Level: 10mm
Water Pump: ON
Current Water Level: 11mm
Water Pump: ON
Current Water Level: 14mm
Water Pump: ON
Current Water Level: 18mm
Water Pump: ON
Current Water Level: 19mm
Water Pump: ON
Current Water Level: 20mm
Water Pump: ON
Current Water Level: 22mm
Water Pump: ON
```

Fig. 22. Water level readings.

For water levels below 25mm, the inlet of the water pump was turned on automatically and the sensor information was published on to the AWS dashboardwhich had subscribed to receive all the sensor values. The illustrations in Fig. 23 show the sensor and pump state that was being published onto the AWS dashboard.

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Water Level

▼ Water Level


```
{
  "Device": "Raspberry Pi",
  "Sensor": "Water Level",
  "Value": 10
}
```


▼ Water Level


```
{
  "Device": "Raspberry Pi",
  "Sensor": "Water Level",
  "Value": 7
}
```


▼ Water Level


```
{
  "Device": "Raspberry Pi",
  "Sensor": "Water Level",
  "Value": 5
}
```


Fig. 23. Water level readings on AWS.

Light Control

The grow lights are controlled depending on the luminous intensity that is detected by the light sensor. The following are the results that were obtainedduring the day on a clear day and night where the luminous intensities both required the required thresholds.

- Results

FOR LUX ≤ 100

To obtain a Lux reading that was below 100, the experiment was conducted atnight with very minimal light. The Fig. 24 indicates the light sensor readings that were obtained by thesensor.

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```
Current Illuminance: 0.9LUX
Grow Lights: ON
Current Illuminance: 1LUX
Grow Lights: OFF
Current Illuminance: 0.8LUX
Grow Lights: ON
Current Illuminance: 0.7LUX
Grow Lights: ON
Current Illuminance: 0.8LUX
Grow Lights: ON
Current Illuminance: 0.6LUX
Grow Lights: ON
Current Illuminance: 0.6LUX
Grow Lights: ON
Current Illuminance: 0.6LUX
Grow Lights: ON
Current Illuminance: 0.7LUX
Grow Lights: ON
```

Fig. 24. Illuminance readings and Grow lights state.

During the night low levels of illuminance are detected so they grow lights wouldautomatically switch on as expected. To verify that this action, the results are displayed on the mobile application interface as shown in Fig 25.

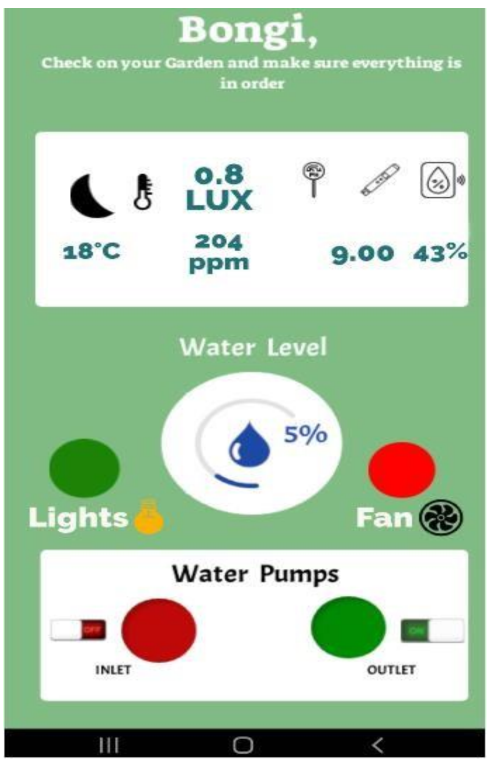

Fig. 25. Light switched for 0.8 LUX.

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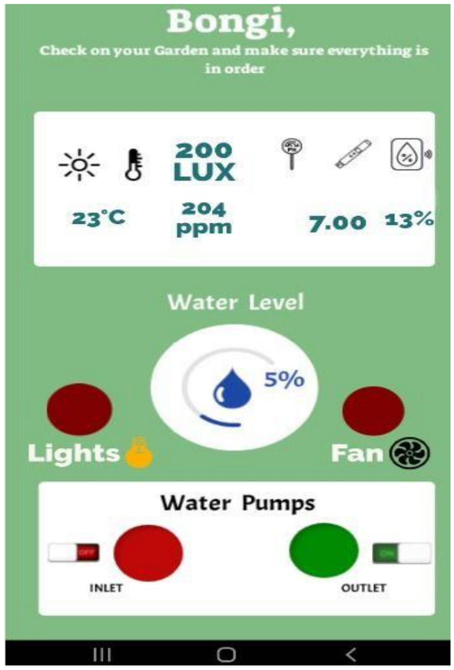

Fig. 26. During the day 200 LUX results for lights being off.

- Analysis

  The ambient illuminance controlled how they grow lights operated. The light sensor records the light intensity data and depending on the value if the LUX value was less than 100, it was considered too dark for the plants so the light would switch on, when the environment LUX was high, i.e., during the day thegrow lights would be automatically switched off.

Fan Control

The fans are adjusted in response to the temperature and humidity of the surrounding environment as sensed by the DHT11 sensor. Climatic tests were conducted on several days to achieve a range of temperature and humidity values. Since temperature changes were minimal, the experiments were conducted duringthe day and night, which supplied the necessary temperature gradients.

- Results

FOR TEMPERATURE $\geq 25\ °C$ AND HUMIDITY $\leq 70\%$

For temperatures that were above 25 $°C$ the atmosphere was considered too hot and considered low humidity, the fans would be switched on to cool the environment.

The Fig. 27 shows the mobile application interface that shows the user, the environment temperature, and humidity when fans were switched on.

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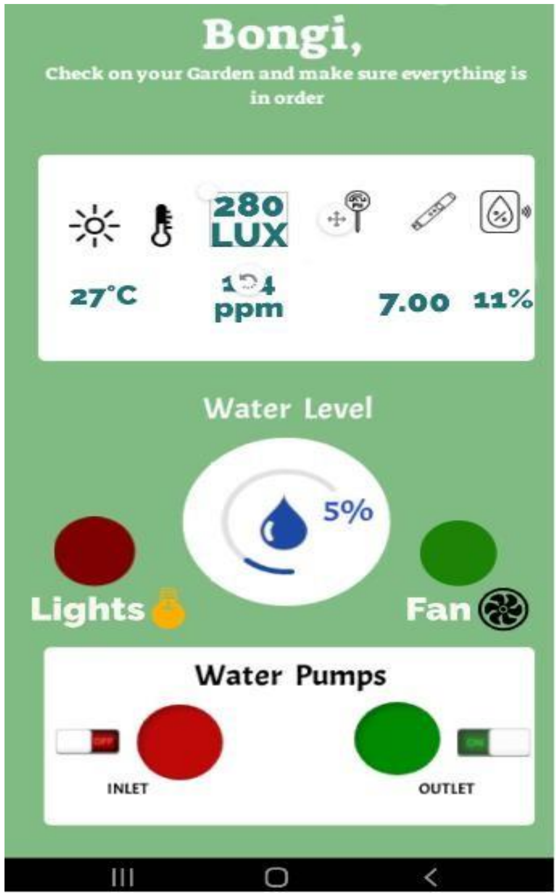

Fig. 27. Fan state for temperature > 25°C and humidity < 70%

IV Conclusion and recommendation for future work

The research conducted extensively explores the application of IoT in hydroponics smart farming, focusing on monitoring and controlling the system. Through meticulous experimentation, the study thoroughly comprehends and effectively applies the operational principles of various sensors to fulfill specific purposes within the hydroponics system. The conducted experiment demonstrates that hydroponics presents a superior alternative to traditional soil-dependent farming, particularly considering the prevailing level of degradation in recent times. Despite the comprehensive nature of this research, there is always room for enhancement. Consequently, it is recommended to incorporate an additional sensor, such as a carbon dioxide (CO_2) sensor, into the system to enable real-time monitoring of plant growth and development.

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