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Integrated Vertical Aquaponics Monitoring System using Hibiscus Sense with Favoriot Platform

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ABSTRACT

Aquaponics combines aquaculture and hydroponics, where fish and aquatic animals are grown in conjunction with soil-less plant cultivation in a circulated environment. Vertical aquaponics typically utilizes the nutrient film technique (NFT) method, employing pipes to continuously stream water to each channel, providing nutrients, water and oxygen to the plants. This project aims to develop a real-time monitoring system for the vertical aquaponics setup, using Hibiscus Sense along with Arduino Mega to measure pH, total dissolved solids (TDS) and water temperature to establish the optimal conditions for Bak Choy growth. All data is uploaded to the Favoriot IoT platform, which includes a dashboard to visualize the information. Results demonstrate a positive correlation between TDS and plant growth, indicating that plants efficiently utilize water nutrients for their development. The linear line values (R) for TDS and growth rate are close to 1.0, with respective values of 0.9234 and 0.9384, underscoring a strong relationship between TDS and plant growth. The ideal conditions for optimal Bak Choy growth are a high TDS value, ranging from 220 to 270 ppm and a pH value of 7.5. Additionally, maintaining a cool water temperature between 26°C and 29°C prevents plant shrinkage due to hot weather. The findings clearly indicate that TDS has a pronounced influence on the growth of Bak Choy, while temperature and pH values exhibit a relatively minor impact.

1. Introduction

Aquaponics is an innovative and sustainable agricultural system that combines aquaculture (fish farming) with hydroponics (soilless plant cultivation). It is a closed-loop system where the waste generated by fish serves as a nutrient-rich fertilizer for plants, while the plants filter and purify the water for the fish [7]. This symbiotic relationship between fish and plants creates a self-sustaining ecosystem that maximizes resource utilization and minimizes environmental impact [4].

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Aquaponics offers several advantages over traditional farming methods. Firstly, it significantly reduces water consumption compared to conventional soil-based agriculture, as water is recirculated within the system rather than being lost through irrigation [11]. Secondly, it eliminates the need for synthetic fertilizers and pesticides, promoting organic and environmentally friendly food production [11]. Moreover, aquaponics can be implemented in various settings, including urban areas with limited space, making it an ideal solution for local food production and food security [8,15].

Research has shown the potential of aquaponics in improving crop yield, water efficiency and nutrient management. For instance, a study conducted by Papathy [13] investigated the nutrient dynamics and plant growth in a vertical aquaponics system [13]. The researchers observed that *Brassica rapa* (Bak Choy) cultivated in this system exhibited robust growth and achieved optimal nutrient uptake [6,13]. The study further explored the nutrient content of the Bak Choy produce, providing valuable insights into the nutritional value of crops grown through aquaponics.

The vertical aquaponics system is under vertical farming and plants are grown vertically above the ground. Vertical aquaponics could better utilize the space and also have more design possibilities to better fit into the environment [8,9,11]. Vertical Aquaponics could be a future concept for planning projects in urban areas to promote and develop sustainable food production [15]. Cultivating vacant lots, converting rooftops and harvesting abandoned buildings and shipping containers into aquaponics systems became a new path in many Asian Countries [5,13].

Technology has pervaded every facet of the industry, including agriculture. The integration of technologies like the Internet of Things (IoT) has played a pivotal role in the substantial and efficient growth of the agricultural sector. IoT has streamlined operations, minimized the need for manual labour and concurrently ensured product quality. By implementing IoT in agricultural processes such as farming, it can now be monitored remotely and effortlessly.

This research project has a dual focus, centred on the development of a monitoring system for vertical aquaponics and an investigation into the influence of fish quantity on the growth of Bak Choy vegetables.

2. Methodology

This project aims to develop a vertical aquaponics system incorporating IoT monitoring devices to ensure an optimal environment for plants and fish. The monitoring setup consists of three input sensors, namely a temperature sensor, pH sensor and TDS sensor [1,7]. These sensors collect data, which is then processed by a microcontroller, the Hibiscus Sense, to execute preprogrammed actions. The microcontroller is also equipped with an embedded Wi-Fi module, enabling it to upload the sensor data to an IoT platform called Favoriot [3,10,14]. The data is stored on the platform for future analysis. Figure 1 illustrates the configuration, with both the input sensors and output display interconnected to the Hibiscus Sense microcontroller board. By obtaining water condition data, the input sensors facilitate data storage and analysis within the microcontroller.

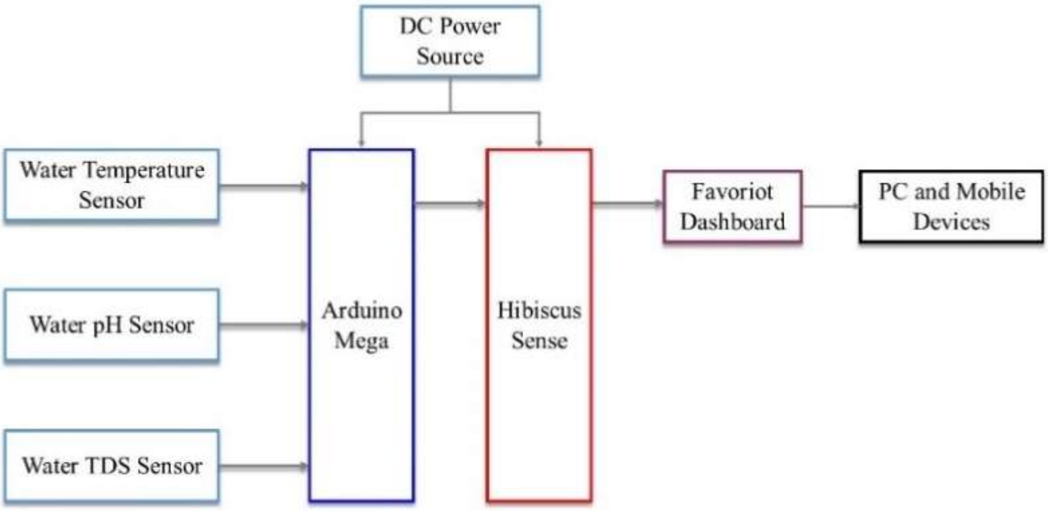


Fig. 1. Block diagram of the vertical aquaponics monitoring system

Figure 2 shows the circuit diagram that connect all the sensor and Hibiscus Sense module to the Arduino Mega before all the data being sent to Favoriot platform. Favoriot was specifically designed for IoT and Machine to Machine (M2M) projects, enabling automated monitoring and control capabilities [12].

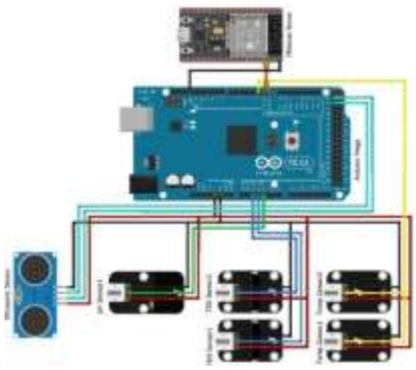


Fig. 2. The circuit diagram of the project

Favoriot is a Malaysian company headquartered in Puchong, Selangor, Malaysia. The platform facilitates seamless data exchange between devices and the cloud using its REST API, allowing devices to push or pull data effortlessly. It serves as an interface for displaying sensor data and interacting with the microcontroller [14]. The data stored in the cloud server holds potential for future data analysis. Moreover, Favoriot offers integration capabilities with Arduino IDE, making it compatible with Arduino development environments [2]. The sequence of the data transfer from sensors to Favoriot server are shown in Figure 3.

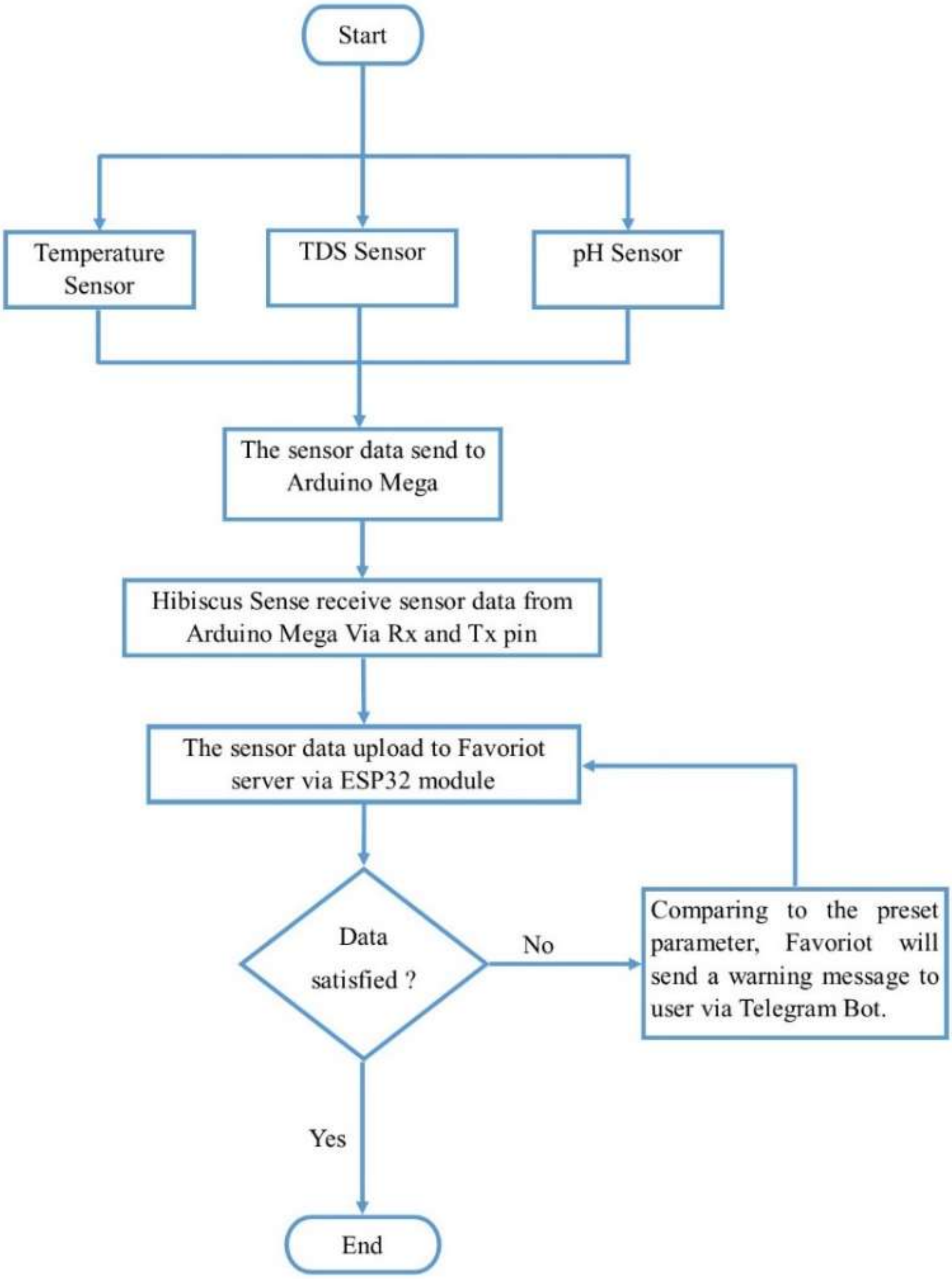


Fig. 3. Flow chart of the project

For this project, a 60L reservoir serves as an aquarium to house climbing perch, locally known as 'puyu' fish. The waste produced by these fish will be utilized as nutrients for the Bak Choy vegetables. The water containing these nutrients will be pumped and channelled to the top of the NFT pipe, where the Bak Choy roots will absorb them. Throughout the experiment, continuous monitoring of water temperature, TDS and pH levels will take place 24 hours a day. The experiment spans a duration of 3 weeks, during which the number of fish will be increased by 5 once a week. The experimental setup of the prototype can be referred in the Figure 4 whereby it shows the placement of the sensor and equipment used in the project.

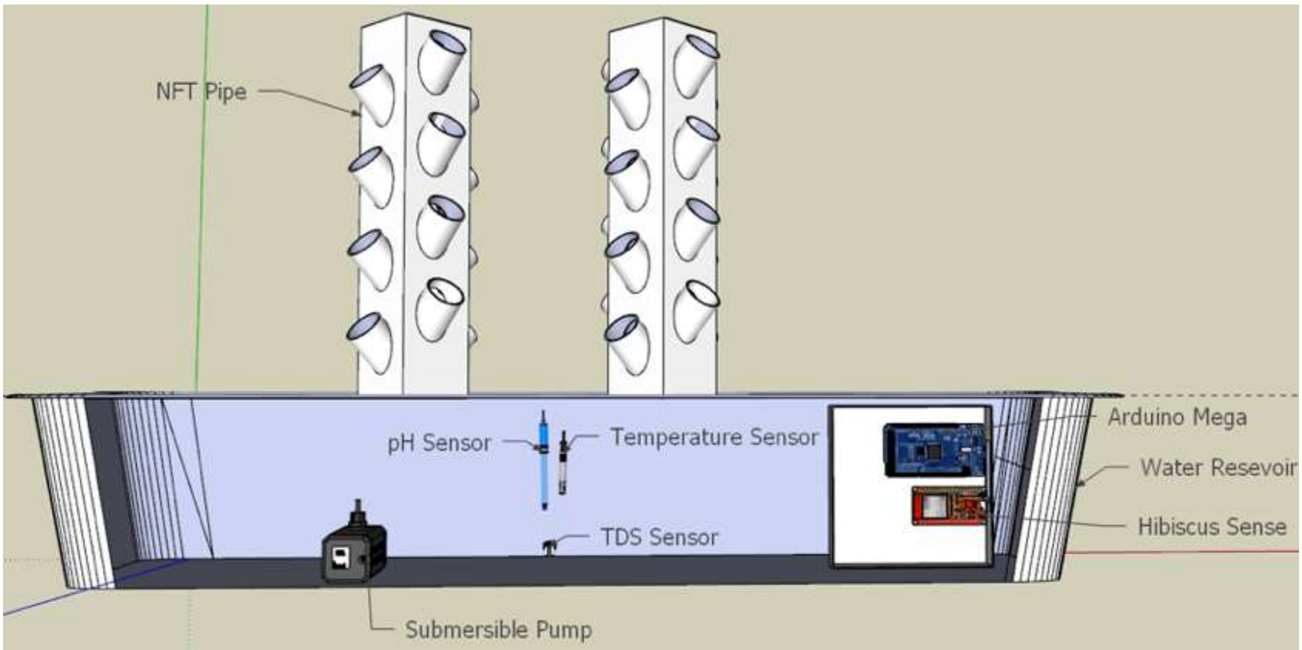
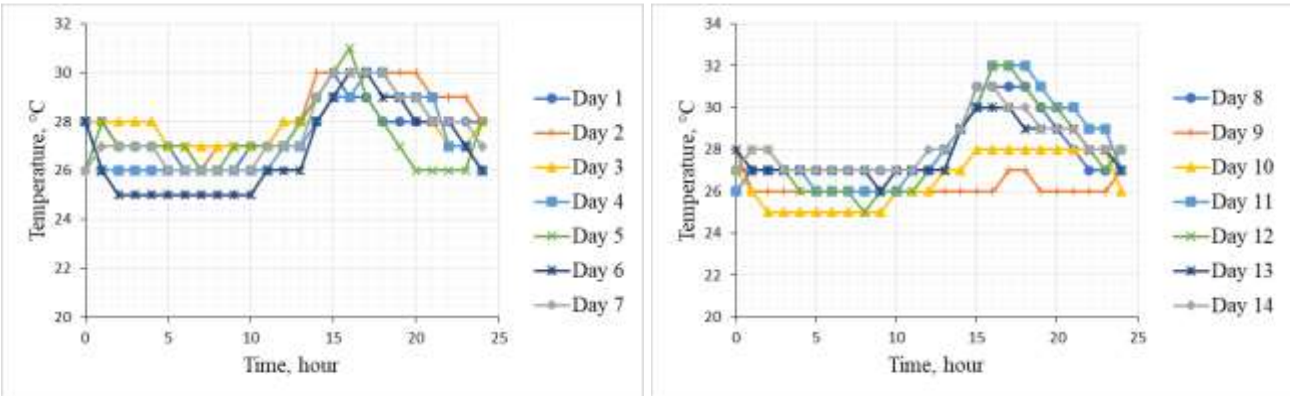


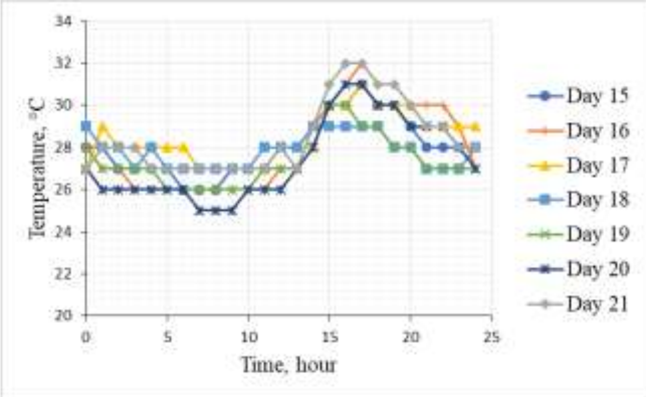
Fig. 4. Cross sectional area of the experimental setup

3. Results

Based on the Figure 5 the water temperature in the vertical aquaponics system remains constant in the early morning (around 2:00 AM to 10:00 AM) due to thermal inertia, similar to the slow warming and cooling of the ocean. As the sun's radiation intensifies towards noon, the water temperature starts to rise, reaching its peak between 3:00 PM and 6:00 PM. After 6:00 PM, the water temperature gradually cools during the night. Rainy days and windy nights can further impact the water temperature.



(a) (b)



(c)

Fig. 5. The water temperature against time in one-hour intervals (a) Week 1 (b) Week 2 (c) Week 3

On the other hand, in Figure 6, the pH level increases daily due to the accumulation of fish waste, particularly ammonia. Maintaining the pH level within the range of 6.0 to 7.5 is essential for successful growth of Bak Choy in the aquaponics system, as excessively alkaline conditions may lead to nutrient deficiencies and poor plant growth [16].

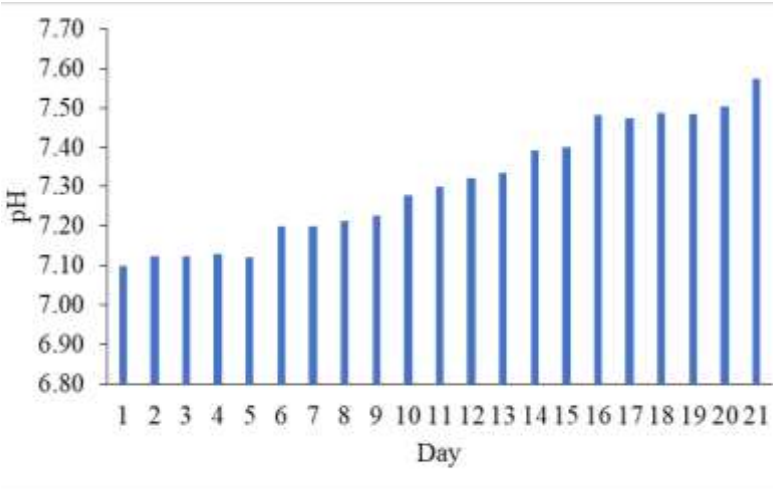
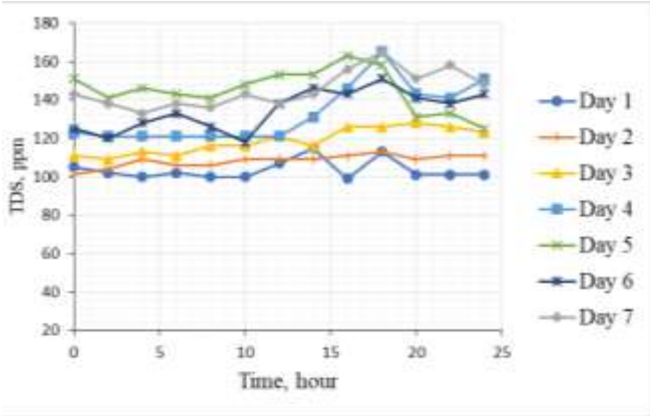
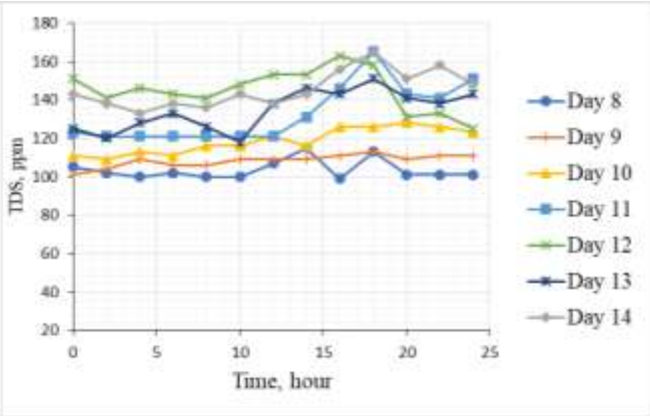


Fig. 6. Average pH value for each day for three weeks

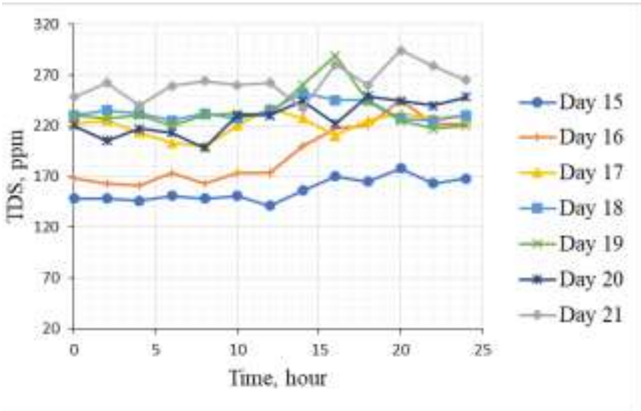
Figure 7 shows how the number of fish affected the Total Dissolved Solids (TDS) value in the water. The results showed that as the number of fish increased, the TDS value also increased. Fish waste was the main factor contributing to the TDS value, as it accumulated in the water. Throughout the three weeks, the TDS value consistently rose due to the continuous accumulation of fish waste. Additionally, a drop in the TDS value occurred on one occasion due to water replacement after algae growth.



(a)



(b)



(c)

Fig. 7. The TDS value against time in two hour-interval (a) Week 1 (b) Week 2 (c) Week

The growth rate of Bak Choy was measured by observing leaf expansion at three time points each day: morning (7:00 AM), noon (1:00 PM) and evening (7:00 PM). Based on Figure 8 and data tabulated in Table 1 shows that Bak Choy exhibits daily growth, with rapid growth during the first 4 days of Week 1. By the end of Week 3, the average growth rate reached 9.6 cm, showing an increase of 3 cm. Notably, Bak Choy tends to grow more during the evening and morning. However, a negative growth rate was observed during noon, as the plants lose water due to evaporation caused by intense sunlight. Despite continuous water supply, the rehydration rate during this time is lower than the evaporation rate, leading to leaf shrinkage. The growth rate remains relatively stable during noon and evening, as they share similar temperature and weather conditions.

(a)

(b)

Fig. 8. Bak choy vegetables during (a) Week 3 (b) Week 4

Table 1
The tabulation data of the growth rate of Bak Choy in the morning, noon and evening

Week	Day	Morning				Noon				Evening			
		S1	S2	S3	Average	S1	S2	S3	Average	S1	S2	S3	Average
1	1	4.9	6.8	9.0	6.9	4.9	6.8	9.1	6.9	4.9	6.8	9.1	6.9
	2	5.1	7.1	9.2	7.1	5.1	7.0	9.2	7.1	5.1	7.0	9.2	7.1
	3	5.3	7.5	9.5	7.4	5.3	7.5	9.5	7.4	5.3	7.5	9.5	7.4
	4	5.9	8.0	9.7	7.9	5.9	8.0	9.7	7.9	5.9	8.0	9.7	7.9
	5	6.0	8.4	9.8	8.1	6.0	8.3	9.8	8.0	6.0	8.3	9.8	8.0
	6	6.2	8.4	9.8	8.1	6.2	8.4	9.8	8.1	6.2	8.4	9.8	8.1
	7	6.3	8.4	9.8	8.2	6.3	8.5	9.8	8.2	6.3	8.5	9.8	8.2
2	1	6.3	8.6	9.9	8.3	6.3	8.7	10.0	8.3	6.3	8.7	10.0	8.3
	2	6.4	8.7	10.0	8.4	6.4	8.8	10.1	8.4	6.4	8.8	10.1	8.4
	3	6.5	8.9	10.2	8.5	6.5	8.9	10.2	8.5	6.5	8.9	10.2	8.5
	4	6.7	8.9	10.3	8.6	6.6	8.9	10.1	8.5	6.6	8.9	10.1	8.5
	5	6.8	9.1	10.3	8.7	6.7	9.0	10.1	8.6	6.7	9.0	10.1	8.6
	6	7.0	9.2	10.4	8.9	6.7	9.0	10.2	8.6	6.7	9.0	10.2	8.6
	7	7.3	9.4	10.4	9.0	6.8	9.1	10.3	8.7	6.8	9.1	10.3	8.7
3	1	7.5	9.6	10.4	9.2	7.1	9.4	10.4	9.0	7.1	9.4	10.4	9.0
	2	7.5	9.6	10.4	9.2	7.3	9.5	10.3	9.0	7.3	9.5	10.3	9.0
	3	7.7	9.7	10.5	9.3	7.4	9.6	10.3	9.1	7.4	9.6	10.3	9.1
	4	7.9	9.8	10.5	9.4	7.6	9.6	10.3	9.2	7.6	9.6	10.3	9.2
	5	8.2	9.8	10.4	9.5	8.2	9.7	10.3	9.4	8.2	9.7	10.3	9.4
	6	8.4	9.9	10.3	9.5	8.0	9.6	10.2	9.3	8.0	9.6	10.2	9.3
	7	8.4	9.9	10.5	9.6	8.0	9.6	10.3	9.3	8.0	9.6	10.3	9.3

The research findings indicate a positive correlation between the TDS value and the growth rate of the plants in the aquaponics system. Based on Figure 9 a higher TDS value indicates the presence of more fish waste dissolved in the water, which serves as a rich source of nutrients for plant growth. Fish waste contains ammonia, which is converted into nitrates by nitrifying bacteria in the water reservoir through the nitrification process. Nitrates are essential nutrients for plant development, supporting the production of chlorophyll molecules necessary for photosynthesis [16]. The positive correlation between TDS value and growth rate suggests that plants efficiently utilize the available nutrients in the water for their growth. The value of R for the linear lines is close to 1.0, demonstrating a strong relationship between TDS value and plant growth rate in the aquaponics system.

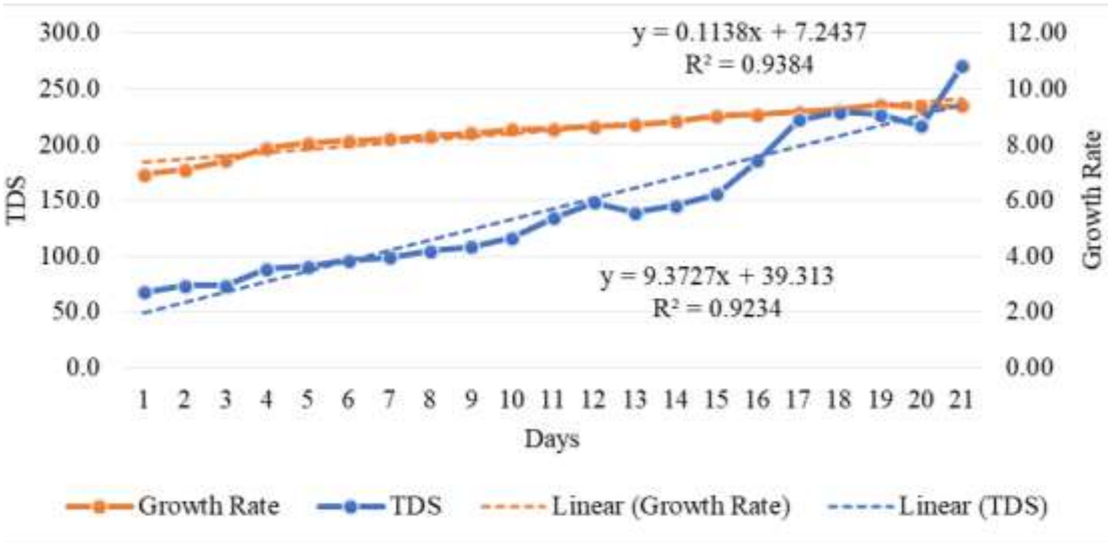


Fig. 9. The analysis of the TDS value effect the plant growth rate

Figure 10 shows the graphical user interface (GUI) of Favoriot platform that shows all the data from all the sensors.

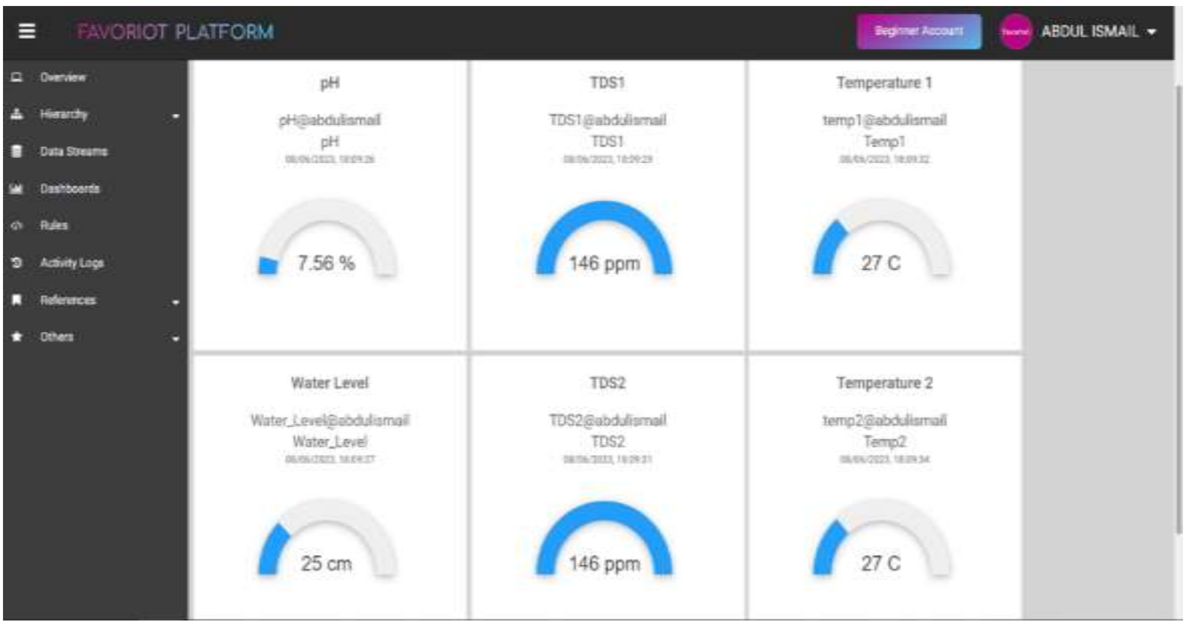


Fig. 10. Favoriot platform graphical user interface for cloud data

4. Conclusion

The research project has successfully developed a prototype capable of monitoring three crucial parameters: pH level, total dissolved solids (TDS) and water temperature in the reservoir. The collected data was effectively recorded and stored in the cloud system of the Favoriot platform, accessible through a user-friendly GUI. The findings revealed that TDS had a significant impact on the growth of Bak Choy. An increase in the number of fish in the system correlated with higher TDS levels, positively influencing Bak Choy growth. While water temperature and pH level did not directly affect Bak Choy growth, they provided an optimal environment for its development.

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