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Design of a Low-cost IoT-based Biofloc Water Quality Monitoring System

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ABSTRACT

This paper proposes an IoT-based BFT water monitoring system that can measure water parameters such as pH, DO, TDS, and EC. The collected data is displayed remotely via the BLYNK cloud and Node-RED via an MQTT broker. Moreover, a mobile application monitors all water parameters in real-time, notifying users when a parameter exceeds the ideal value. This study suggests that the proposed system based on IoT is an excellent option for a cost-effective BFT system.

1. Introduction

Addressing the challenge of feeding the growing human population, which is expected to reach 9.6 billion by 2050, facing the scarcity of essential natural resources required for food production, such as land and water, is an exceedingly critical endeavor [1]. Aquaculture has emerged as an ideal food production option in many countries. However, the aquaculture industry has yet to face some serious challenges. For instance, aquaculture has been accused of being unsustainable because of the effluents discharged into the environment, which contain excess organic matter, nitrogenous compounds and toxic metabolites [2]. Other serious accusations include the competition for land and water, the overexploitation of ocean fish stocks, the dispersion of pathogens, and the development of antibiotic-resistance genes [3,4]. To overcome these challenges, the biofloc technology (BFT) system has been proposed as an outstanding technology capable of solving some of the environmental and economic challenges faced by traditional aquaculture production systems [5].

BFT is based on the recycling of toxic waste and uneaten feed pellets into floc biomass, which is considered a source of nutrition. This process is achieved by promoting the growth of microorganisms

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(autotrophic bacteria) cultured by adding carbohydrates as organic carbon sources (molasses, cassava, tapioca, glucose, and rice bran) and probiotics to the BFT system in order to control the carbon-to-nitrogen ratio (C/N ratio) so that the bacteria can absorb the waste ammonium for new biomass production [6]. BFT is noted for its positive role in maintaining water quality, enhancing fish reproduction, providing an alternative source of nutrition, and promoting the overall welfare and growth of fish in the culture units [7]. Given these advantages of the BFT system, it is generally understood that the success of this technology rests upon its ability to remove, recycle or control harmful nitrogenous substances in the culture system [8]. Water quality maintenance and monitoring in aquaculture, especially in BFT, are essential practices aiming at the success of the microorganism's growing cycles. Dissolved oxygen (DO), Total dissolved solids (TDS), electronic connectivity (EC), pH, flocs volume (FV), temperature, salinity and alkalinity are some examples of parameters that should be continuously monitored in BFT [9]. The comprehension and understanding of water quality parameters in BFT are crucial to correctly developing and maintaining the BFT system. For example, safety ranges of pH, FV, TDS, EC, and temperature will lead to healthy growth and avoid mortalities.

The BFT system involves heterotrophic, chemosynthetic, and autotrophic bacteria, which consume alkalinity, leading to a reduction of alkalinity and pH in the system. Autotrophic bacteria consume more alkalinity due to the consumption of a higher amount of inorganic carbon [10]. Ebeling *et al.,* [11] noted that 3.57 g of alkalinity are required by heterotrophic bacteria to convert 1 g of ammonium-N into 8.07 g of microbial biomass with 9.65 g of carbon dioxide as the by-product. Crab *et al.,* [12] reported that reductions in pH below 6.5 or increases above 9.5 will not only affect the microbial community in biofloc and associated characteristics and quality, but they will also affect the cultured organism.

Water temperature is an important environmental factor influencing the growth of aquaculture organisms, and an appropriate water temperature should be maintained for the optimal growth of microorganisms present in the biofloc system. Water temperature directly affects not only the microbial community and metabolism of aquaculture organisms, but also the DO concentration in the water [13]. In order to maintain a stable biofloc culture, it is necessary to establish the optimum operating temperature by determining the contact point between the optimal temperature of water for breeding aquaculture organisms and the growth of microorganisms. Although many researchers reported that 26–30 ◦C is the most suitable temperature for the biofloc system, Ogello *et al.,* [13] suggested that an intermediate water temperature of 20–25 ◦C may be best suited to obtain stable flocs in BFT. In order to maintain a stable biofloc culture, it is necessary to establish the optimum operating temperature by determining the contact point between the optimal temperature of water for breeding aquaculture organisms and the growth of microorganisms.

BFT is confronting numerous issues because of sudden weather changes in water quality parameters. Still, this manual testing method is time-consuming and continuously produces inaccurate results as parameters to measure changes in water quality [14]. It is unavoidable to become more intelligent in order to effectively monitor water quality and feed. However, few studies address this issue. Aliamed and Ahmed [15] proposed a monitoring and control system for BFT. The proposed system is able to control the motor feeder, water pump, heater, cooler fan, oxygen pump, and water filter based on the water parameters such as temperature, pH, TDS, and water level. Also, the system has a mobile app for monitoring and controlling purposes. Bakhit *et al.,* [16] developed low-cost IoT solutions with LoRa-based BFT real-time monitoring, stream analytics, and predictive capabilities. R-studio, combined with the LAMP server, was used to perform stream analytics and HTML dashboards. Goswami *et al.,* [17] in this work use the BFT monitoring system with pH, TDS, temperature, and EC sensors. The finding shows that using BFT is much better compared to recirculation aquaculture systems (RAS) in terms of water quality. underwater weight measurement system by utilizing MATLAB and image processing, the BLYNK platform was used for remote monitoring. Mozumder and Sagar [18] propose an IoT intelligent water monitoring system for BFT. The water components such as DO, nitrogen, pH, water temperature, nitrate, ammonium, and carbon dioxide can be displayed on smartphones. Moreover, the system automatically controls the actuators to resolve the water quality issues if the water quality level exceeds a certain threshold. This paper aims to design a biofloc water quality monitoring system to measure the pH, TDS, EC, and temperature in real-time.

2. Methodology

Demonstrates the system design as shown in Figure 1. The monitoring system consists of a sensor node that mainly consists of two-layer structures; the lower layer is for sensing the water parameters such as pH, TDS, EC, and temperature, while the upper layer is the application layer, which is responsible for the system node-red dashboard. The issue with Node-RED is the inability to access the dashboard remotely; to overcome this issue, MQTT-Broker is able to publish the data globally over the internet. BLYNK cloud and Node-RED provide remote access using laptop and the BLYNK mobile app. Figure 2 shows the experimental design of BFT monitoring system.

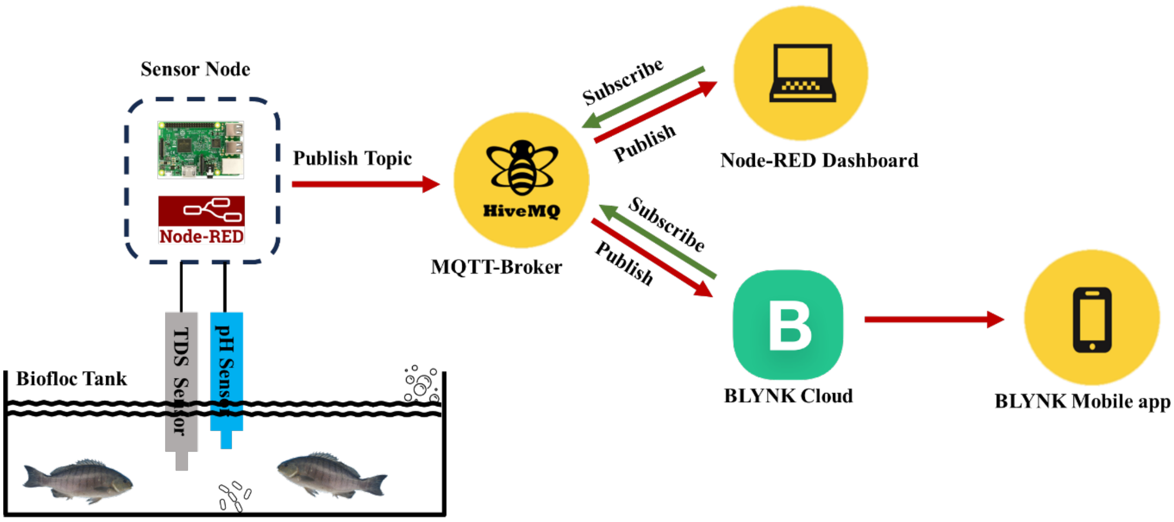


Fig. 1. The proposed system architecture of the IoT BFT water monitoring system

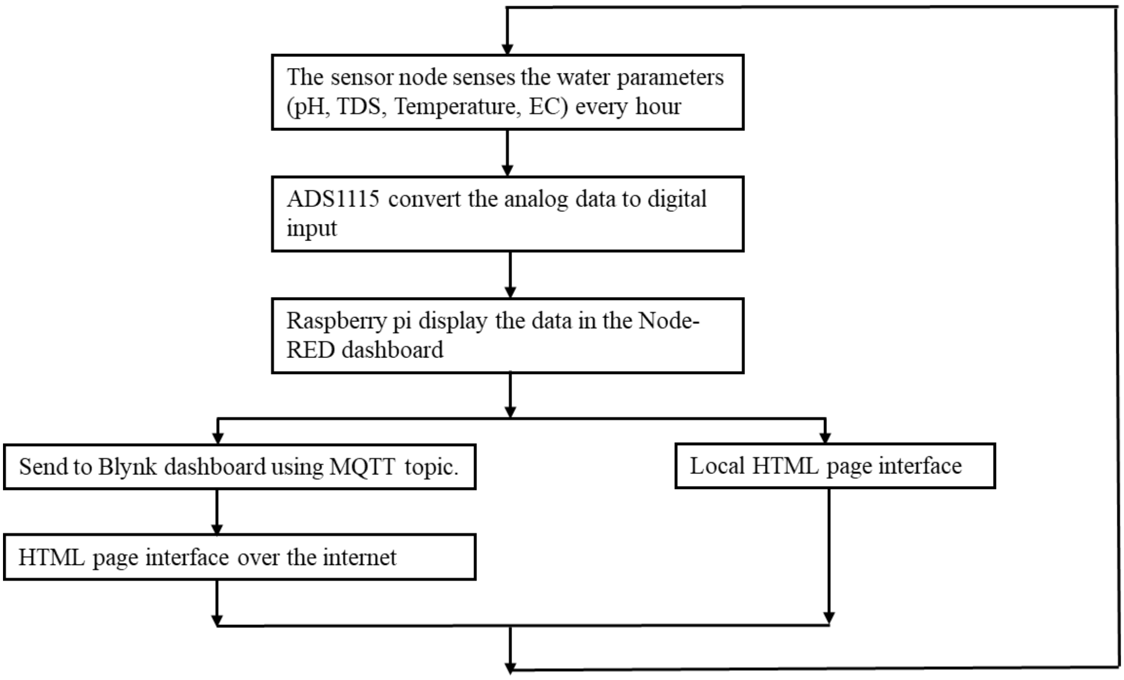


Fig. 2. The experimental design of BFT monitoring system

Figure 3 shows the Node-RED flow is a comprehensive monitoring system that gathers data from various sensors using MQTT input nodes, including temperature, pH level, electrical conductivity (EC), and turbidity, subscribed to specific topics. This data is displayed in real-time on corresponding UI gauge nodes, with color-coded indicators, and is also visualized historically using UI chart nodes, presenting trends over time. The system allows for remote monitoring via Blynk IoT output nodes, which transmit data to a Blynk dashboard. Comment nodes provide clarity on the flow's structure, and the MQTT configuration connects to an MQTT broker. The UI elements are organized into groups, such as "Temperature," "pH," "EC," and "TDS," within a "Biofloc Monitoring System" tab. Additionally, the Blynk IoT client is configured with an authentication key and template ID for seamless interaction with the Blynk cloud platform, offering a comprehensive solution for monitoring environmental parameters.

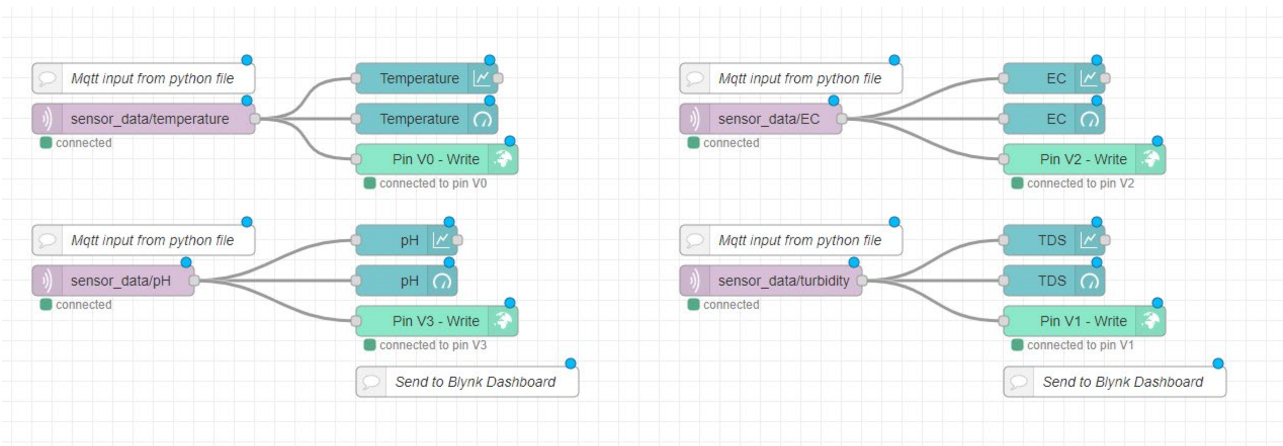


Fig. 3. The proposed system architecture of the IoT BFT water monitoring system

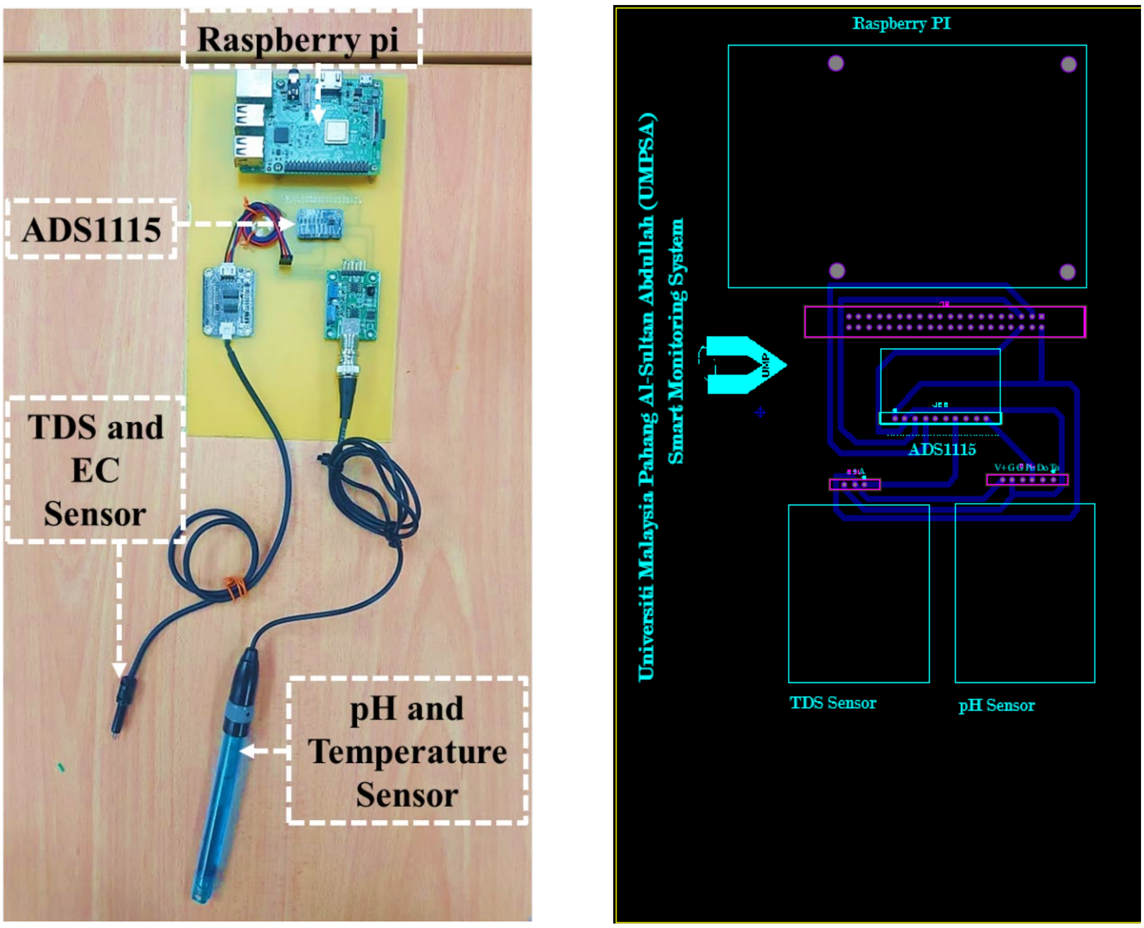
Figure 4 (a) shows the single-sided PCB was designed using Proteus software, as shown in Figure 4 (b). Meanwhile, the outputs of pH, temperature, EC, and TDS sensors are in the form of an analog voltage variable; thus, an analog-to-digital converter (ADC) ADS1115 module has been used.

The prototype is designed to meet operational requirements under adverse environments, e.g., hot, humid, and rainy weather conditions. Thus, the deployed sensors are industrial grade and standard certified to ensure high precision, accuracy, and reliability, the system implemented in biofloc farm name “Delek Aquaculture Farm” located at lot 2224 Lornng Mujir, jalan Kampung Delek Kiri, 41250 Kalng, Selangor, Malaysia. as shown in Figure 5. In addition, sensors are calibrated well so that accurate data can be obtained, as referred to in Table 1.

For sensor accuracy, the proposed system was compared to manual measurement. The comparison is obtained by the mean and standard deviation.

Table 1
Sensor specification

Measured Parameter	Measuring range	Accuracy
Temperature [19]	-10 to +85 °C	± 0.5 °C
pH [20]	0-14	± 0.1
TDS & EC	0 ~ 1000 ppm	± 10%



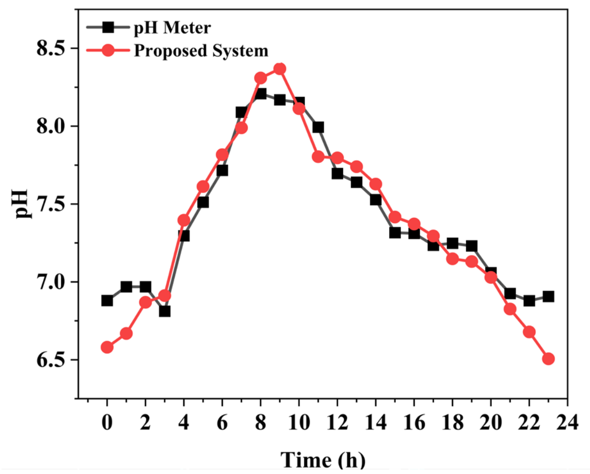
(a) (b)

Fig. 4. (a) Final PCB sensor node prototype (b) Schematic Design of sensor node

Fig. 5. Sensor node at Delek Aquaculture Farm located at Klang, Selangor, Malaysia

3. Results and Discussion
3.1 Sensors Accuracy Results

Minabi *et al.,* [21] reported that TDS and EC are proportional to the FV. The intolerable amount of TDS in BFT is shown to be about 5000 to 20,000 mg L^{-1}. With an increase in TDS from 5000 to 20,000 mg L^{-1} the FV shows interment between 20- and 90-ml L^{-1}. TDS and EC can be considered FV indicators. The sensors were tested for six months under different environmental conditions. During this period, accuracy is tested and verified to ensure that the predictive analytics based on real-time data are accurate. To validate the accuracy and reliability of the sensors and their real-time data, an on-shelf independent system for temperature, TDS, EC, and pH was taken as a reference to compare with the proposed system. Table 2 shows summary statistics of the data, including the mean and standard deviation values for manual method and proposed method. The maximum accuracy percentage error is ≈10% which is acceptable [22]. Figure 6 shows the results of the manual measurement vs. proposed system for pH, TDS, EC, and temperature.



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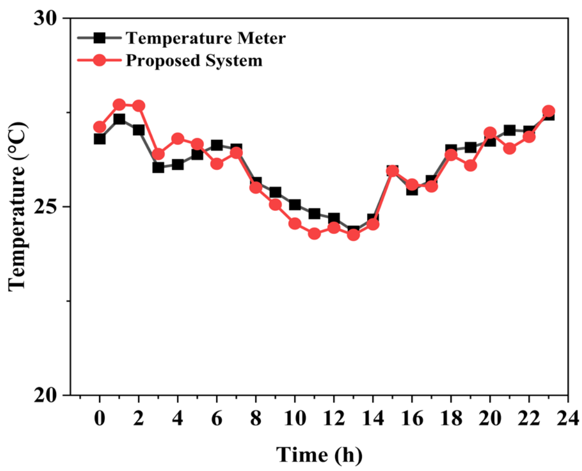

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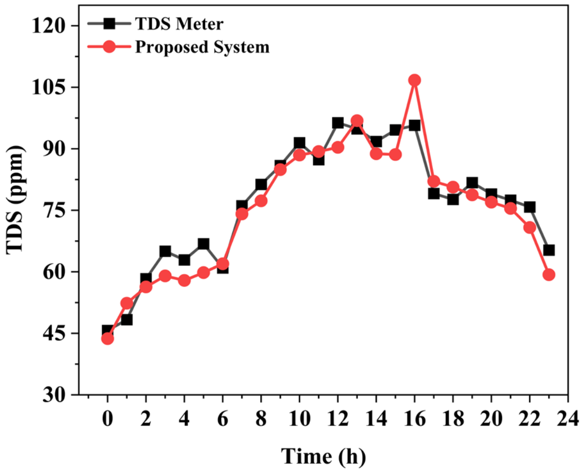

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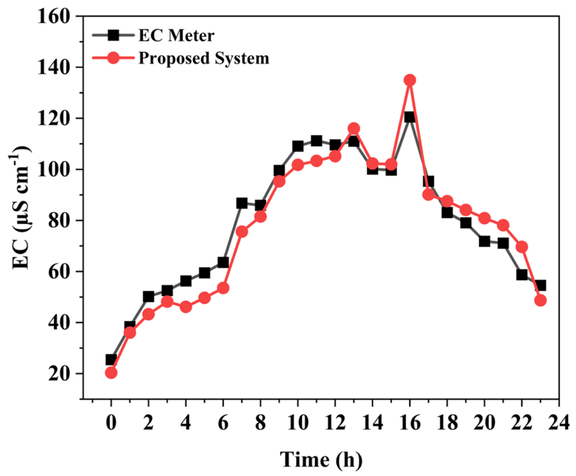


(d)

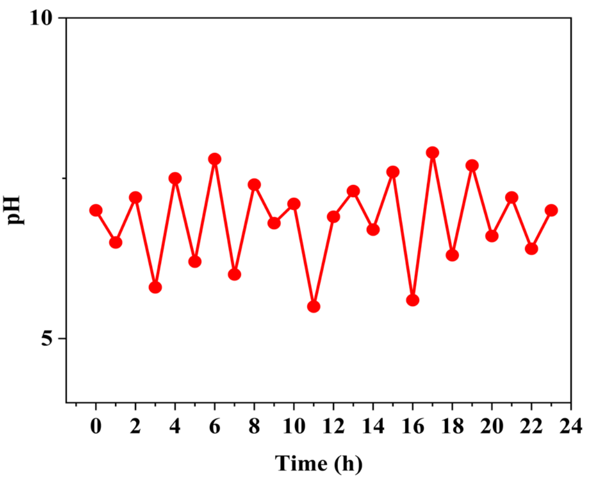
Fig. 6. (a) Data validation manual measurement vs. Proposed system pH (b) Temperature (c) TDS (ppm) (d) EC (µS cm^{-1})

Table 2
Data validation manual measurement vs. proposed system

Parameter	Mean of the manual method	Mean of the proposed method	Standard deviation of the manual method	Standard deviation of the proposed method
Temperature	26.49	26.69	3.53	3.84
EC	228.89	227.31	25.51	28.12
pH	7.40	7.37	0.45	0.53
TDS	126.64	125.02	14.44	15.46

3.1 Real Time Data

The healthy threshold level for pH, TDS, EC, and temperature, ranges between 6.8-8.5, 0-600 mg/L, 30-2000 µS/cm, and 24 °C to 30 °C, respectively. Figure 7 shows that the DO, EC, pH, TDS, and temperature readings were all normal for 1 day.



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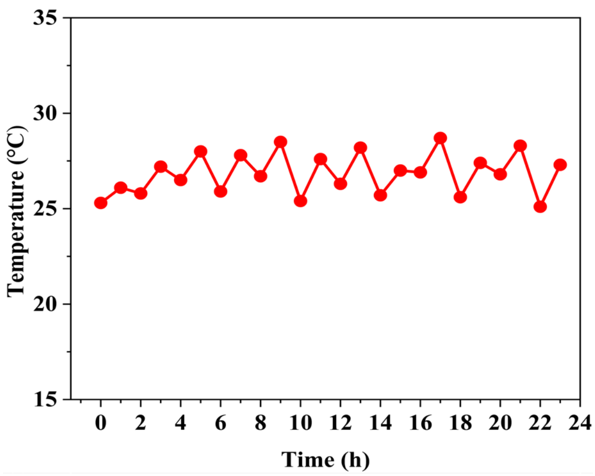

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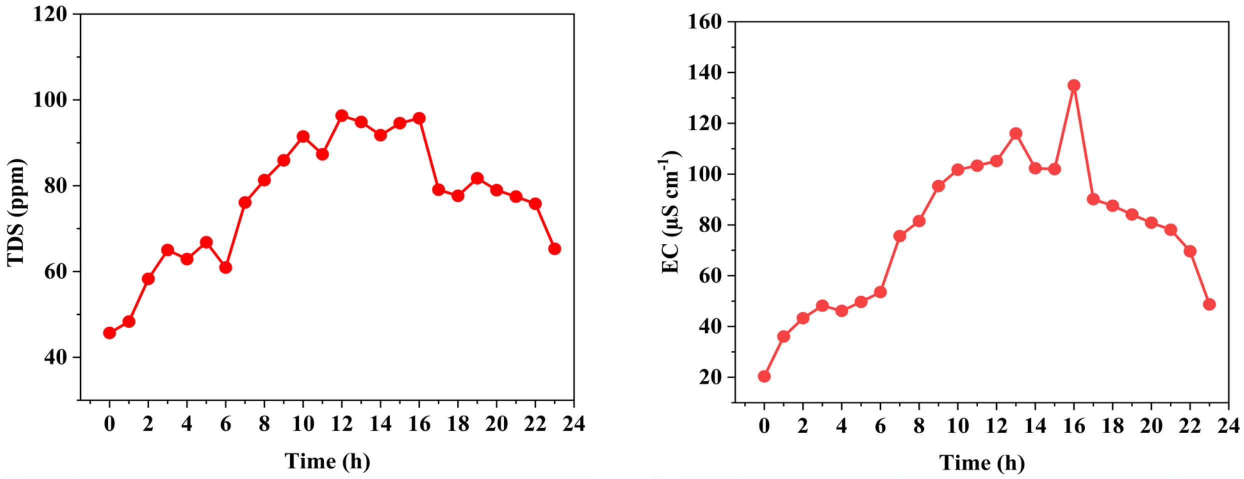
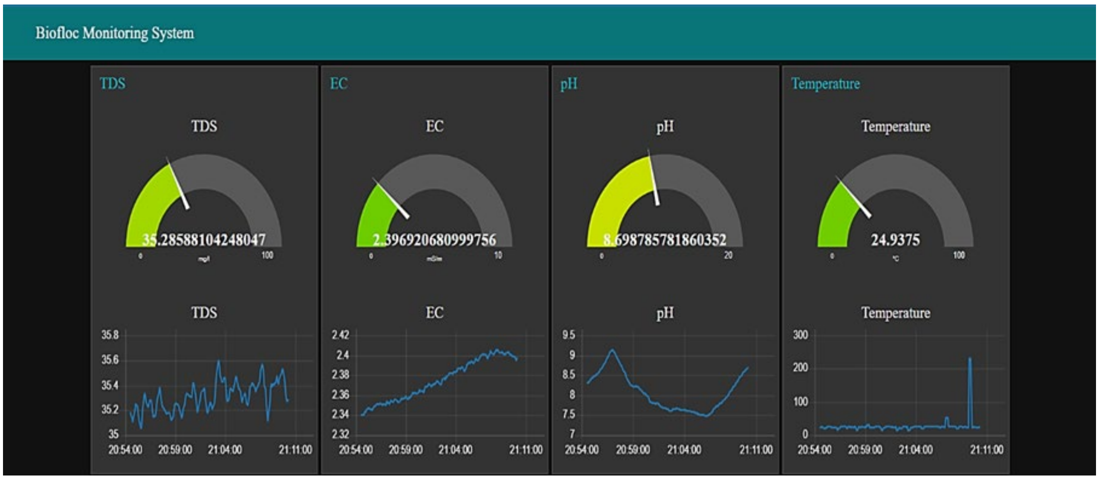


(c) (d)

Fig. 7. (d) Real-time data for one day pH (b) Temperature (c) TDS (ppm) (d) EC (µS cm^{-1})

Figure 8 (a) shows the real-time Node-RED dashboard data which is monitored by the system. These values are changing in real-time and updated regularly as the sensor value is also changing. Figure 8 (b) shows the real-time BLYNK cloud dashboard. which provides real-time and alarm message if any sensing parameter crosses the threshold level this app section will notify the user.



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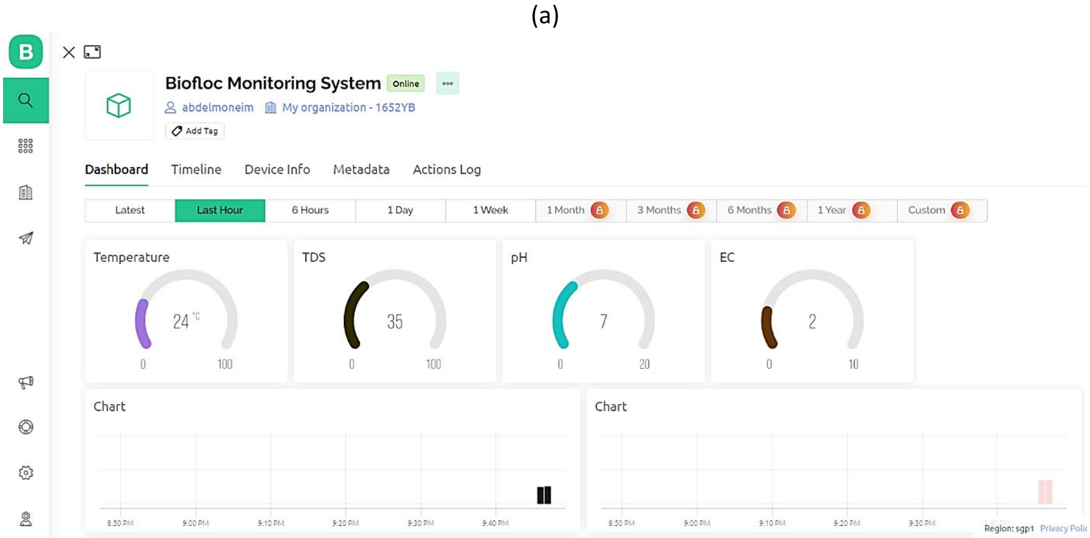

(b)

Fig. 8. (a) Real-time dashboard Node-RED dashboard (b) BLYNK cloud dashboard

4. Conclusions

The suggested system represents a cost-effective and efficient solution for managing BFT systems. Monitoring in real time and acting quickly can help fish grow sustainably in BFT systems, making sure the best conditions for aquaculture and lowering the risks that come with changes in water parameters. This study suggests that the proposed system based on IoT is an excellent option for a cost-effective BFT system.

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