Development of a Low-Cost Solar Powered & Real-Time Water Quality Monitoring System for Malaysia Seawater Aquaculture: Application & Challenges

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ABSTRACT

Harmful algal bloom (HAB) has been a long-term threat to the ecosystem as it pollutes water and reduces the safe water usage worldwide. Therefore, scientists and researchers dedicated tremendous time and efforts to prevent the growth of algal by monitoring and profiling the water quality index. However, provided that the expensive cost of the commercialised sensor, including the dynamic and causality of algae, complicated the process, this article discusses on the progress of a low-priced real-time monitoring system for water quality through the solar panel to perform preliminary studies on the water quality data. Profiling environmental readings is a crucial step in gaining an insight into the algal bloom growth. Furthermore, the real-time data collection from the system was continuously performed at the sea, leading to consistent data transfer to the server through a 3G network despite the remote monitoring. Notably, the two benefits of this system included the solution to the laborious process, which was based on manual sample collections. The second benefit was the database, which provided information on safe WQI for the fish farm and insight about algae growth, which could be used in the predictive modelling phase.

CCS Concepts

• Hardware→Emerging Technologies• Computer systems organization→Real-time systems.

Keywords

Real-Time, Big Data, Water Quality Index (WQI), Water Quality Monitoring System, Algae Bloom, Temperature, Turbidity, pH, Salinity, Dissolve Oxygen, Total Dissolved Solid (TDS).

1. INTRODUCTION

Harmful algal bloom (HAB) becomes a threat to water sources as the population of algae rapidly grows, leading to the increase in nutrients and minerals, which promotes the excessive of algal growth [1] [2]. Furthermore, the toxin produced from the algae encourages the growth of decomposers, which leads to water pollution [3] and limits access to safe water usage [4]. The lack of understanding of the causality and dynamic of algae community leads to the possibility for the prediction of algae growth to be a challenging task [5][6].

However, machine learning (ML) is capable of gaining insight from the given data of the algal community. The clear description of the key factors of algal growth and their relationships contributes to an efficient prediction of algal bloom and the prevention of its growth. Provided that this process should be initiated by a collection of big and real-time data, this research aims to propose a monitoring mechanism for the profiling of the environmental readings, such as temperature, total dissolved solids (TDS), pH level, turbidity, salinity, and amount of dissolved oxygen. Besides, the system is available at a reasonable price and enables remote real-time measurements, which keeps human intervention at the minimum and allows a complete system to be developed at a low price.

The next section of this article is Section 2, which describes the background study and parameter initialization. This is followed by Section 3, which presents the development of the method and architecture of water quality monitoring system based on the integration of sensor and analytics, while the preliminary results of the monitoring of water quality parameters are illustrated in Section 4. The conclusion of this study is presented in the final section of this article.

2. RELATED WORK

Extensive research was conducted by ecology researchers on algae growth through the monitoring and prediction of algal growth in the freshwater or brackish water [7] - [12]. As a result, it was found that environmental factors facilitated algae growth. To illustrate, Huang et al. [5] listed twenty environmental parameters, which facilitated cyanobacteria blooms in freshwaters, such as water temperature, ambient temperature, turbidity, solar radiation, total suspended solids (TSS), pH, salinity, and chlorophyll-a. Furthermore, Wells et al. [13] performed extensive research on the past and present state of algal blooms by focusing on the global impacts of climate change in the marine planktonic system and describing the several environmental factors, which underwent alterations upon the pressure of climate change. The factors included grazing, precipitation-induced nutrient inputs, ocean acidification, light, stratification, and temperature.

Several readings of the parameters such as temperature, turbidity, TDS, DO, salinity and pH were profiled through manual sampling and human observation on the algal blooms, which required researcher presence in situ to record readings within certain intervals (e.g., weekly) [14]. In a study by Harun et al., [15] a suitable water quality standard for the growth of fish and algae in Malaysia was recorded. Therefore, several parameters developed by Harun, such as temperature, pH, DO, turbidity, TDS, and

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electrical conductivity from water quality index (WQI) [16]. This article aims to study the value of the sensors to investigate the suitability of the seawater for normal use, and the parameters selected in this study are presented in Table 1 below:

Table 1. Conducive fish production and algal growth according to Malaysia national water quality standards [15]

Parameters	Malaysia	General targeted condition for fish and algae growth
Temp (C)	Normal + 2 ℃	Depending on type of fish, the growth of the algae increases with increase in temperature.
pH (index 0-14)	6-9	Normal pH ranges from 5 to 9.
DO (mg/L)	5-7	**The lowest DO value as a support to the majority of fish of diverse types was from 4 to 5.
Turbidity (NTU)	5	Turbidity determines the water solid contents, which may clog the membrane.
TDS (mg/L)	500	An excess of suspended solids and nutrient in water sources
EC (μS/cm)	0.5-1.5	Most natural water and content of dissolved ions, which lead to increased conductivity with higher total ion concentration.

3. MATERIALS AND METHOD

The proposed framework for the development of a low cost and solar-powered real-time monitoring system for water quality is presented in Figure 1. This framework was studied based on past work in [17] with some changes in hardware to suit the low-cost concept for seawater and additional of predictive modelling phase. Figure 1 framework consisted of five phases, and three of the phases were subphases of data acquisition. Other phases included data management/visualisation and data modelling. Data management was performed in this study, in which data acquisition was conducted continuously for a minimum of one to two years to observe the relationship between the parameters, which would trigger algal growth. This section will discuss on design of the real time monitoring system in each phase, and it will be separated into specific sections.

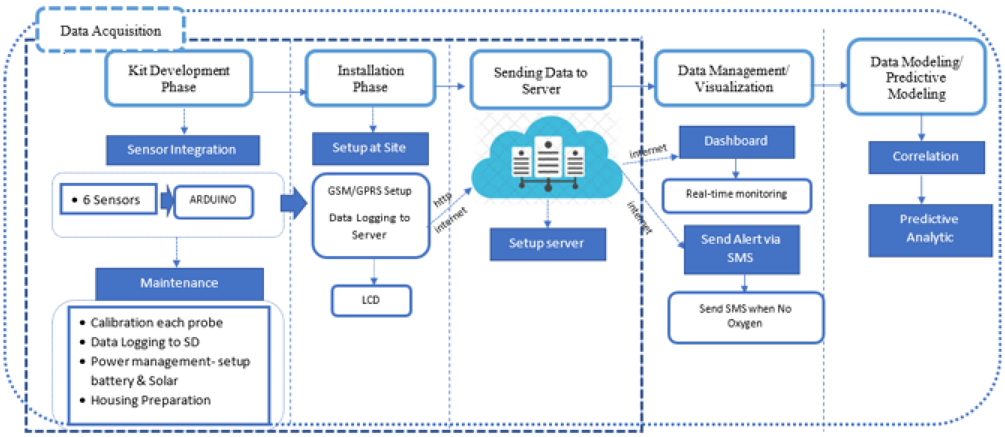

Figure1. Framework of complete low-cost real-time water quality monitoring system.

3.1 Data Acquisition

The architecture of the system during data acquisition could be divided into two major sections, namely hardware and software. These sections were present in the three phases, including kit development, installation, and transmission of data to the server. In the case of hardware, kit development phase comprised all the required sensors, while the software section comprised the development of a water monitoring programme using the C/C++ language in Arduino Bluno. Arduino Bluno (on-board BLE chip: TI CC2540). This tool functioned as a micro-controller, which controlled the data transfer for all sensors connected to it. Meanwhile, the involved sensors functioned as the parameters probe for the water monitoring system. The specifications of the cost of the sensors are summarised in Table 2. Based on the table, the total cost for all the sensors amounted RM1,512 or 365$. Upon the comparison with the commercial sensor, one unit of the sensor would amount to RM20K or 4829$. Furthermore, the development of the system was 20 times cheaper than the commercial sensor, proving that the low price of the water monitoring system could be achieved and the cost of the system application could be reduced. A water-proof box should be used for housing as the installation of it at the sea is essential. Notably, the box was designed carefully along with a rechargeable battery, solar, and solar controller, which contributed to the water-proof and highly heat-resistant properties of the box, which also exhibited chemical and atmospheric agents. Complete design of the water-proof panel box is presented in Figure 2.

Table 2. Sensor specification and cost

Sensor/ Equipment	**Cost (RM)**	**Sensor/ Equipment**	**Cost (RM)**
Arduino	80	Temperature	11
Expansion Shield	36	Turbidity	40
pH	119	Solar Panel & Controller	133
DO	687	Battery	44
TDS	40	Jumper Wire	3
EC	284	Waterproof Box	35
		Total Cost	**RM1,512**

Figure2. Designed of solar-based water-proof panel box

The real acrylic panel box, which contains the Arduino board, gsm 9000a shield, rechargeable battery, solar panel, solar controller, the LCD for display, and sensor boards are presented in Figure 2 above. Outside of the box is an antenna used to send or receive data using the 3G mobile network.

3.2 Installation Phase

Known as Sg. Udang, this site in Penang is a common fish farm in Malaysia, which is located in the middle of the sea. All the required materials were transported on a common fish farm boat, as shown in Figure 3. Meanwhile, the existing fish farm plant shown in Figure 4 is an area of approximately 250 meters per square, in which local Malaysian fish, such as Siakap, Jenahak, and Kerapu are produced at the farm. Furthermore, the water level of the plant is 20 cm higher than the water level on a normal day.

Upon the completion of the kit development, installation of the kit was performed at the fish-farm site remotely. Provided that this study needed to ensure that sufficient power was supplied to the sensors and Arduino, rechargeable battery with a solar panel was also installed at the site. It is noteworthy that the physical design of the system was tightly tied and located in a cylinder pipe to hold the sensors together and avoid the scattering of the sensors from their original position during high and low tide of the installation in the water body, as shown in Figure 5.

Figure3. Preparation and transportation to the site.

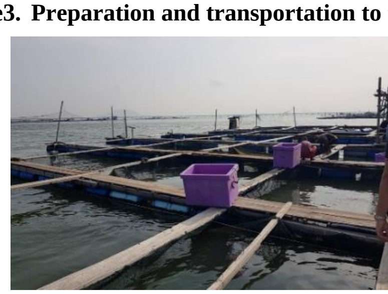

Figure4. An Image of the fish farm plant.

Figure5. Complete solar-powered panel box installed with cylinder pipe and soaked in the seawater.

Before installation, sensors underwent calibration upon the requirement to ensure that the values were correct. A minimum of 12 V from the sunlight is essential for the solar panel to function properly. In this study, the solar panel received adequate sunlight as the installation site was located in the middle of the sea. After the confirmation that the solar was connected to the battery through the solar panel controller, the panel box was ready to be closed and tightly tied beside the solar panel before being left. A total of four units of panel box were developed and installed at a different side of the fish farm to monitor the algal population by profiling the water quality parameters.

3.3 Data Management/ Visualization

Data management and visualisation phase involved the implementation of a dashboard using free php and XAMPP, including an open-source cross-platform web server solution. Web interface monitoring of real-time water quality assisted in visualising the current measured value, while the data stored in the server aided the data-mining process. Data logger to the cloud was conducted using Thingspeak server for a temporary period for testing, which was relatively stable, satisfactory, and hosted in the web.

The second part of the progress focused on the real-time of the monitoring system. A comprehensive study was conducted on the current real-time system or models and the languages used to design the system. Currently, real-time data were transferred from the sensor and Arduino to the Thingspeak server using GSM Sim900a module, followed by the recording of data every minute. As a result, the importance of analysing each measured data for future profiling and prediction was demonstrated. Additionally, the data volume was expected to be larger upon being recorded for each minute.

4. RESULTS & DISCUSSION

The research team visited the fish farm site a few times to develop a system according to the terms and prerequisites. After a week of installation, the offline data recorded at 1 pm for one week were analysed and elaborated, as shown in Figure 6 to Figure 11.

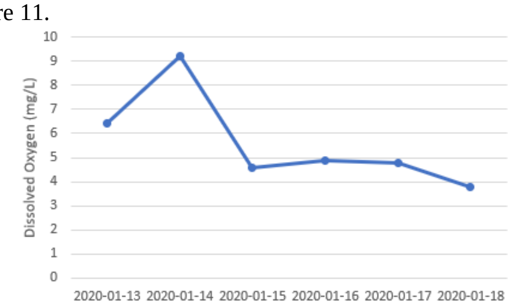

Figure6. Dissolved oxygen measurement of Sg. Udang.

Figure 6 illustrates the measurement of the dissolved oxygen at Sg. Udang plant, which was recorded in January 2020, particularly when North-East Monsoon was approaching its end. It could be seen that the measurement was significant as it ranged from 4.5 tp 9.5 mg/L or PPM. Following the production of oxygen by the sea through phytoplankton photosynthesis, DO level rose when directly exposed to the sunlight [18]. It was also indicated that the average reading of DO amounted to 5.62, with the majority of the readings amounting to 4.5 and aligned with the minimum DO (refer to Table 1). Therefore, this measurement supported the range of a high population of diverse fish species, which was from 4 to 5 mg/L.

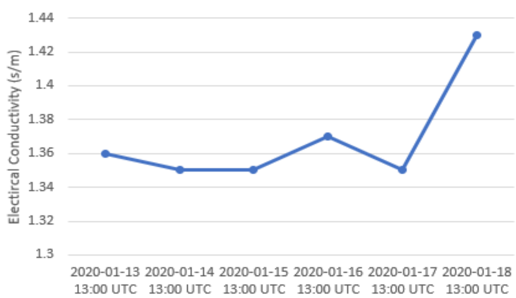

Figure7. Electrical conductivity measurement of Sg. Udang.

Figure 7 illustrates the electrical conductor (EC) measurement of Sg. Udang within the 7-day installation. Most natural water comprises dissolved ions, which leads to an increase in conductivity as the total ion concentration increased [19]. The average reading of EC on a regular day ranged from 1.4 to 1.5 (s/m). Furthermore, the ability of a solution to exhibit conductivity increased when the salt content increased. Following the capability of EC to describe salinity, a high salinity level indicated high EC measurement, while low salinity level indicated the opposite. Upon a visit to the site, other research teams applied commercialised salinity sensor, followed by a lab testing. After the analysis between the results of the parameters, the measurement for salinity should be "offset" to ± 2, which was in agreement previous studies [20]. Additionally, freshwater fish and saltwater fish might require different levels of water conductivity to survive.

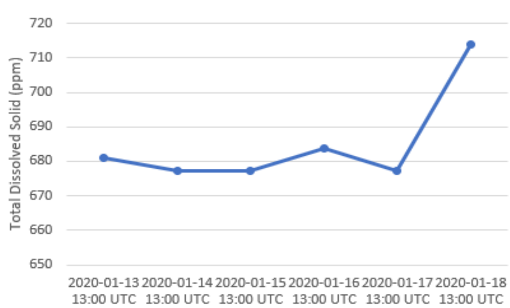

Figure8. Total dissolved solids measurement of Sg. Udang.

Figure 8 illustrates the measurement of TDS with an average reading of 685 ppm within seven days after installation. The combination of total organic and inorganic substances, which were found along with water molecules including minerals and salts, was measured through TDS. Notably, the increase in TDS could lead to contamination and impurities in water resources [21]. Overall, the reading of TDS was not adequate to indicate the pollution occurring in the water for the fish farm plant.

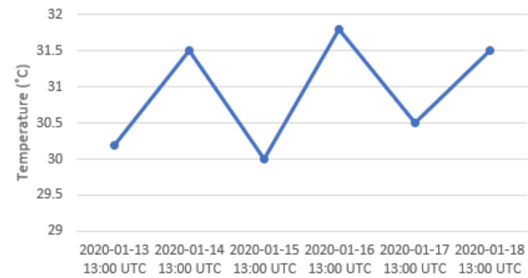

Figure9. Temperature measurement of Sg. Udang.

Based on Figure 9, which presents the measurements of temperature in Sg. Udang, significant water temperature was found, with approximately 30 ˚C average reading. The higher fluctuation of ambient temperature was found with a maximum of +/- 2 ˚C, indicating a normal temperature, as seen in Table 1. Overall, it was indicated that the water temperature was influenced by the current weather in the North region, which was hot and dry.

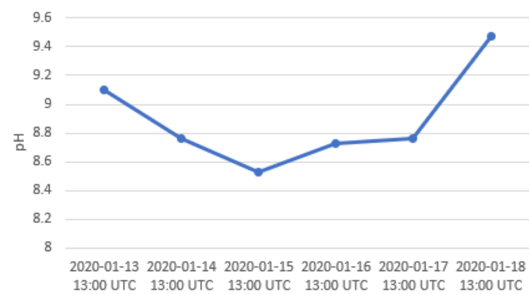

Figure10. pH measurement of Sg. Udang.

Figure 10 illustrates the measurement of water pH in Sg. Udang within two days. The average pH reading within the seven days ranged from 8 to 9, which was normal and ideal for the growth of the fish. This process was based on the daily cycle, while the photosynthesis process involved the consumption of carbon dioxide (CO_2) by the phytoplankton. As a result, the pH level was reduced at noon [18]. It was indicated by Figure 6 to 11 that these important parameters contributed to the good conditions for aquaculture, as seen in Table 3.

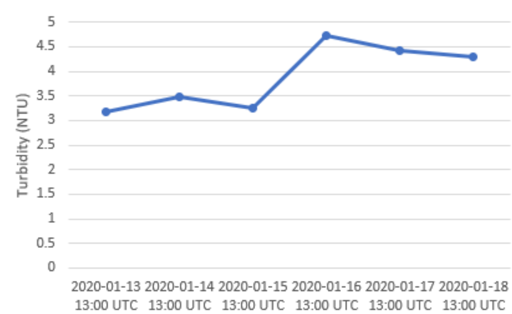

Figure11. Turbidity measurement of Sg. Udang.

Turbidity refers to the amount of suspended sediment in water (e.g., water clarity) [18], and its value is considered important in studying algae growth. Based on the turbidity measurement on Sg. Udang plant shown in Figure 11, the average reading of turbidity on a regular day amounted to 3.89 NTU, which was considered low. It could also be seen from the figure that the turbidity level was high on certain days, and it was low on some other days. The turbidity level also increased in heavy rain [18].

Furthermore, the growth of algae increases water turbidity. Algae block the passing of light by limiting its spectrum under the water surface. The changed features of light were found to impact the reproductive behaviour of fish [22] [13], leading to indirect influence on fishery production. Therefore, turbidity plays a significant role in profiling the growth rate of algae and preventing the proliferation of algae.

In the case of the power supply, the use of rechargeable battery and solar panel contributes to the sustainability of the system as the solar continuously supplies the required power by charging the battery during the day. When the battery reaches its full capacity, it can supply adequate power for the system to operate at night. Overall, it was indicated by the parameter that the quality of water at the fish farm is ideal for the reproduction of fish and sustainability of the safety of the water sources.

5. CHALLENGES & FUTURE WORK

A month of installation was followed by a visit to the site as a non- stable measurement was shown through the dashboard of the monitoring system. Subsequently, it was observed that the probe was surrounded by macroalgae. According to Radmer [23], algae consisted of two categories, namely microalgae and macroalgae. Specifically, macroalgae refer to bigger alga, which is commonly known as seaweed, while microalgae refer to small algae commonly known as phytoplankton. Several places at the fish farm were found to be affected by the growth of macroalgae, as shown in Figure 12 and Figure 13. Therefore, it could be predicted that despite the good water quality index for fish growth, it might be deteriorated by the macroalgae.

Figure12. Probe surrounded by seaweed or macroalgae.

Figure13. Wooden road surrounded by macroalgae that are coral-like Macroalgae.

All the probes were cleaned and tested again. Although it could be seen that some probes might require a replacement, only two probes were affected out of four of the water stations installed at the site, which was possibly due to the place and the environment. Specifically, two affected water stations were located at a place with a stronger wind-wave compared to other water stations. Therefore, it was proven that the fish farm site w the growth of algae.

In the next installation, an improvement in the installation method was attempted by placing all the probes inside a waterproof box instead of outside of the water to protect the probes from the macroalgae. The seawater was then pushed by the water pump relay inside the box and sensed by the sensors. Although the probe/water station unit was functioning properly, the only required changes were the positioning of the water station, as shown in Figure 14. This method might be efficient in preventing the probe from being surrounded by the macroalgae, in which additional power sources were needed for the probe to function due to higher consumption of power by the wire pump.

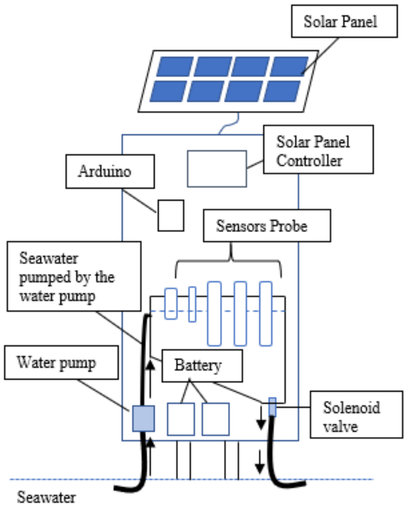

Figure14. Future work for improvement in positioning the water station using water pump.

Based on Figure 14, the positioning of the water involved the absorption of seawater by the water pump, which was then sensed by the sensors. In this case, the solenoid valve would be involved in pumping out the seawater into the water sources. Notably, the advantages of the new design included 1) the prevention of the probe from being surrounded or damaged by the seawater ecology and 2) the ease of process for future maintenance. This advantage included the facilitated maintenance such as replacing any probes or specific needs by the fish farm community and the reliance on the community during the testing period instead of paying a frequent visit. However, the continuous experiment is still being conducted on the functions of the water pump, threshold, maintenance, and the required power consumption.

6. CONCLUSIONS

The selection of the sensor is compatible and sufficient for the measurement of water parameter based on the system suggested in this study to monitor water quality. The suggested system was installed and assessed in a real-world surrounding, which contributed to a dependable performance data. Furthermore, all parameters were interrelated to indicate the growth of algae and successfully monitor water quality. As a result, the maximum present consumption of 24 mA was recorded from the energy analysis in every hour of use, while the range of the maximum 3G reading exceeded 50 km and located at the middle of the sea-based on the extrapolated data. This research effectively formulated and applied its main aim for environmental supervision, particularly in WQM. The price of Arduino boards, circuits, 3G module and solar panel amounted to approximately RM1000 and above, with the majority of the price was transferred to housing infrastructure and sensors. By keeping the price at the minimum, different levels of users could increase the efficiency in monitoring and automating their fish farm site. Besides, large data for the seawater water monitoring system database were created, in which machine learning or data mining could thoroughly be performed, followed by robust predictive modelling, which was adaptable to conditions besides the conditions of the specific fish farm site.

7. ACKNOWLEDGMENTS

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