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Portable Spectrophotometer for Water Quality Monitoring in Recirculating Aquaculture Systems

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Abstract. Water quality management in aquaculture is vital, as aquatic life is highly sensitive to changes in parameters such as inorganic nitrogen, pH, temperature, presence of gas, turbidity, and dissolved oxygen. The water quality must therefore be consistently monitored and controlled for the aquatic life to maintain optimum health, productivity, and quality. Currently, the problem arises when water quality analyses are time-consuming and could not be done rapidly. Thus, this project focused on designing a low-cost portable wireless spectrophotometer system for rapid water quality measurements. The hardware components used in the system consist of a C12880MA mini spectrometer chip, a Bluetooth module, and an Arduino Nano microcontroller. The microcontroller was programmed using the Arduino IDE environment and run by an Open-Source Miniature Spectrophotometer (OSMS) application. In this study, a portable wireless spectrophotometer that can measure water quality parameters such as turbidity is demonstrated. Water samples from the recirculating aquaculture system (RAS) were used to measure the water turbidity. The main objective of the study is to verify the applicability of the portable spectrophotometer for rapid and reliable water quality monitoring. Results showed that the spectrophotometer measurements had R^2 of 0.94 when regressed on the turbidity of the RAS water samples. This showed that the customised portable spectrophotometer could be instrumental for a low-cost and rapid water quality monitoring in RAS.

1. Introduction

There are many challenges in managing an aquaculture production system. One of them is the accumulation of nitrogenous waste such as ammonia and its biological nitrification products, which are nitrite and nitrate. To overcome this situation, various aquaculture systems use different nitrifying ecosystems in biofilters and bioreactors, which contribute to the system's unique nitrogen conversion. Recirculating aquaculture systems or also known as RAS provides a continuous and controlled habitat for the fish, providing optimal and totally controlled production of a variety of types of fish and other aquatic life. RAS gives fish a constant and controlled environment that enables optimal and completely managed production [1].

Aquatic animals raised in a controlled environment like in RAS are extremely sensitive to changes in variables including pH, temperature, and gas concentrations. The changes of water quality does not only affect fish well-being but also the performance of nitrification. For example high turbidity and low dissolved oxygen level can reduce the performance of nitrification which will result in the accumulation of ammonia. So, the water quality must be constantly checked and managed to keep the fish healthy and quality at their best. Water quality has a direct influence on the metabolic rate, growth, and survival of aquatic animals. On top of that, water resources could contain other types of toxic compounds. Based on Razman et al [2], arsenic, iron, lead, and other heavy metals commonly found in groundwater sources in agricultural areas, radioactive waste landfills, and municipalities can cause water pollution that is harmful to living things.

Conventionally, water quality measurements involve on-site water sample collection, which is often sent to the laboratory for analysis. This process takes several days to be completed. More recently, efforts have been done for more rapid water quality monitoring using modern sensing technologies. With the advancement of electronic technology, many in-line and on-line sensing systems can be customised for water quality monitoring in RAS [3] especially using wireless data transmission such as the Internet of Things (IoT). IoT gives an advantage in terms of rapid data acquisition. Nevertheless, the system often also requires rapid calibration of the sensor nodes, high maintenance and needs to be powered continuously. Investing in this technology often increases the production cost which hinders adoption, especially among small-scale farmers. Thus, more studies and research in developing a practical and low-cost sensing system are much needed in the aquaculture industry.

Very recently, Laganovska et al [4] managed to design a low-cost standalone portable spectrophotometer that could measure the intensity of transmitted or absorbed light spectra transmitted by water. Spectrophotometer is a common lab instrument used for water quality analysis. As the spectrophotometer developed by Laganovska was a standalone and portable, it could be installed on-line into RAS systems which allows rapid measurements. Using IoT technology, the collected data could be displayed via a computer interface or a specific smartphone application.

Based on Laganovska's work, this study focused on calibrating the light absorbance measurements acquired from the portable spectrophotometer across a range of water quality directly sampled from RAS facilities at Universiti Putra Malaysia. The scope of the study was focused on relating the absorbance measurements with water turbidity of water in RAS.

2. Materials and Methods

The study was conducted at RAS facilities of the Faculty of Agriculture, University Putra Malaysia. In total, six RASs were utilised for water sampling where each consist of four tanks namely fish tank, solid removal tank, biofilter tank, and sump tank. Three samples from each tank were collected for water turbidity and absorbance measurements. As reference, water turbidity and absorbance of tap water samples was also being measured.

2.1. Portable spectrophotometer system

An open source portable spectrophotometer electronic circuit designed by Laganovska et al [4] was rebuilt and used in this study. The data acquired from the system can be both displayed via a dedicated smartphone application or a computer interface, allowing users either to gather and view data on the move or set up a continuous experiment. The system consist of five main components, which are a mini spectrometer chip (C12880MA, Hamamatsu Photonics K.K, Japan), an Arduino Nano microcontroller, a Bluetooth module, a cuvette cell and a LED light [4]. The microcontroller was programmed using the Arduino IDE environment and run by an Open-Source Miniature Spectrophotometer (OSMS) application. The spectrometer chip acts as the detector of the transmitted light from the LED, passed through the water sample in the cuvette cell. It can measure absorption at wavelengths ranging from 450 nm to 850 nm.

However, since our assembled system used a white LED which only emits up to 750 nm, thus absorption can be measured at the wavelength limit of 750 nm. The system was placed in a closed dark container during measurements to ensure no significant amounts of light entering the measuring device. The total bill of materials cost of the system was around USD250.00. Only one prototype of the system was built and this prototype is used to measure water quality of sample from six RASs.

2.2. Data Collection

A total of 24 different samples were collected from six RASs, each consisting of four tanks (i.e. fish tank, solid removal tank, biofilter tank and sump tank). The water quality in each RAS varied. All the absorbance measurements using the spectrophotometer from each sample were collected 10 times and the average were recorded. The turbidity measurements of these samples were measured using a turbidity metre (2100Q, Hach, Malaysia) for correlation analysis. To obtain the average turbidity for each sample tank, a total of three readings were accumulated.

3. Results

The turbidity measurements of 24 samples from six different RASs were recorded in Table 1. Each RAS shows different turbidity values ranging from 2.7 NTU until 25.2 NTU. The four tanks of each RAS had a turbidity value that was approximately similar to each other. Taking RAS 6 as an example, the average value for the fish tank, biofilter tank, solid removal tank and sump tank had a range from 7.3 to 7.7 NTU with an average of 7.5 NTU. Tap water is used to act as a control sample. The turbidity of tap water measured using the turbidity metre was 0.5 NTU which is within the theoretical value of below 1 NTU [5].

Table 1. The average turbidity values for each RAS

Sample Tank	Average Turbidity (NTU)					
	RAS 1	RAS 2	RAS 3	RAS 4	RAS 5	RAS 6
Fish	19.1	24.0	33.5	9.0	24.1	7.7
Biofilter	19.5	24.0	2.8	9.3	20.8	7.3
Sump	20.1	20.2	2.7	9.1	22.7	7.3
Solid Removal	19.0	21.0	2.6	8.7	25.1	7.7
Average RAS Turbidity (NTU)	19.4	22.5	2.9	9.1	23.2	7.5

RAS 5 had the highest average turbidity value with 23.2 NTU followed by RAS 2 with 22.5 NTU, RAS 1 with 19.4 NTU, RAS 4 with 9.1 NTU and RAS 6 with 7.5 NTU. The RAS with the lowest turbidity value is RAS 3 with only 2.9 NTU. The turbidity value can provide information about the clarity or cloudiness of water inside the RAS. It measures the degree to which suspended particles or solids are present in the liquid. It could be used as an indicator of when water in the RAS system needs to be changed or discarded. Studies showed that turbidity can negatively affect fish feeding and growth at levels from 25 to 70 NTU [6].

In this case, RAS 5 had the most cloudy or murky water due to a significant concentration of suspended particles and solids although it is still within the acceptable range. Generally, the high turbidity value is usually caused by the feeding activities in RAS for example excessive feeding or improper feeding practices can lead to uneaten feed and waste particles suspended in the water. Another reason is the accumulation of solid waste such as faeces, and excess organic matter, which can contribute to higher turbidity levels. Inadequate waste removal mechanisms or insufficient filtration can also result in the buildup of suspended particles. Excessive suspended particles can clog filters, reducing their efficiency and potentially leading to system malfunctions or failures.

Opposing from RAS 5, RAS 3 had the lowest turbidity value which indicates that the water is clear and has minimal suspended particles or solids. Maintaining a low turbidity level is important especially for aquatic life as clearer water with low turbidity promotes optimal oxygen exchange and minimises potential health problems. In addition, maintaining low turbidity helps the biofiltration system for nitrification operate effectively. Although RAS 5 had the highest turbidity value when compared to other RAS setups, it is still considered within the standard operation where high turbidity levels for fishes are typically considered to be above 50 NTU.

3.1. Light absorbance measurements

The average water absorbance values across 450 to 700 nm for each RAS were between 0.08 to around 0.12 AU (Figure 1). Each of the RAS has a similar pattern of absorbance where the values had sharply increased at around 470 nm before they gradually decreased towards higher wavelengths. Clear separation of absorbance can be observed at around 615 to 700 nm. Absorbance measurements at 648 nm were further analysed to be regressed with water turbidity values for correlation analysis.

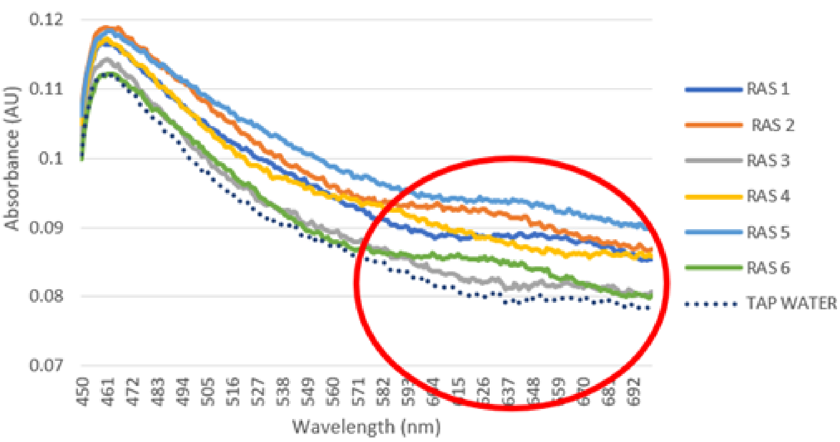

Figure 1. The average water absorbance values across 450-700 nm for each RAS compared to tap water. Measurements at 648 nm were further analysed to be regressed with water turbidity values

3.2. Correlation between light absorbance and water turbidity

Figure 2 shows the goodness-of-fit of a regression model and indicates how well the turbidity can explain the variation in the light absorbance at 648 nm of the samples. The R^2 of the regression has a value of 0.9442 where it generally suggests a strong relationship between absorbance and turbidity. It indicates that approximately 94.42% of the variability in the absorbance can be explained by the turbidity in the regression model.

4. Conclusions

Results showed that the spectrophotometer measurements had R^2 of 0.94 when regressed on the turbidity of the RAS water samples. This showed that the low-cost customised portable spectrophotometer could be instrumental for a rapid water quality monitoring in RAS. Further work could be conducted to gather more data and develop a machine learning model for water turbidity prediction.

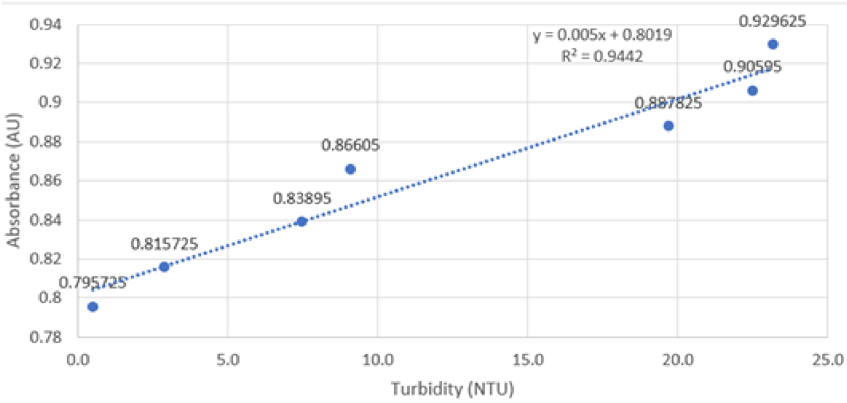

Figure 2. Linear correlation of water absorbance at 648 nm wavelength with its turbidity

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