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A Reliable Architecture for IoT-based Aquatic Monitoring System of Coral Reef and Algae

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ABSTRACT

The coral reef population worldwide faces degradation issues due to various human-related factors such as pollution, overfishing, collecting live corals for the aquarium market, warm climate, thermal stress and ocean acidification. These factors lead to an imbalance in the natural ecosystem where the coral reef and algae reside. Coral reefs are susceptible to the changes in their natural ecosystem. This work aims to study the optimum condition for the coral reef and algae to healthy flourish. The main factors that influence the growth and survival of coral reefs and algae are also studied. Thus, this paper presents a proposed monitoring system-based IoT to monitor the coral reef and algae ecosystem. The system also intends to introduce a regulatory mechanism which can regulate the main factors identified to maintain an optimum condition for the coral and algae to prosper. In order to support the intention, a reliable network system and communication are needed to ensure that accurate information can be obtained. The system consists of sensors, microcontrollers, and a web application for monitoring real data of three different parameters most affected the ocean water: pH, temperature and salinity.

1. Introduction

Aquatic life such as coral reefs and algae is a part of the aquatic ecosystem. About 25% of the ocean's life depends on healthy algae and coral reefs. Due to various human-related factors such as pollution, overfishing, collecting live corals for the aquarium market, warm climate, thermal stress and ocean acidification the coral reefs face the issue of population diminish [1]. This huge population needs to maintain a congenial environment so that the algae and coral reefs can grow healthily. Factors such as pollution due to vast development and climate change have harmed the environment such as water pollution [2]. Algae are the majority of coral reef communities [3]. Naturally, tropical reefs contain many algae species essential for a healthy ecosystem. As coral reefs depend on algae

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for survival and play an important role as a spawning and feeding ground for important marine life, the destruction of both algae and coral reefs affects the whole marine ecosystem.

Coral reefs are sensitive to climate change, and coral bleaching occurs as sea temperatures increase [2,4,5]. To note, the corals exposed to changes in salinity show higher survival than those exposed to changes in temperature and in freshwater that produces normal salinities much higher than the world average [6,7]. It was found that the global average annual tolerance limits for coral reefs are 21.7 to 29.6 °C for temperature and 28.7 to 40.4 g/kg for salinity [8]. Salinity is one of the important factors that affect the growth of algae and it can grow in various ranges of salinity. For example, the growth of the algae Nannochloropsis can be found in minimum salinity which is 15 g/kg [9]. Other studies confirmed that the algae species were able to tolerate growth at the optimum temperature range of 25-30°C [10,11] and this finding was within the range (27-30°C) reported by Renaud. This indicates that algae have different ranges of tolerance and adaptability to their environment. Other than light, temperature and salinity are the main factors contributing to corals reef growth. Coral's survival is prolonged in salinity stress exposures compared to temperature stress [6]. Karuppananpadian *et al.,* [4] found out that if the temperature exceeds the optimal value it will lead to corals bleaching. While other studies showed that sudden changes in salinity can cause the death of coral reefs [6,12,13]. Coral reefs require a water temperature range between 18 to 32°C [14]. If the temperature is above or below that range it can cause stress to the coral. Therefore, it is very important to monitor water temperature fluctuations to help understand the temperature changes that cause corals to bleach and eventually die. Chung and Yoo [15] found that the optimal parameter of sea water for coral reef life is a temperature of 30°C and a salinity of 33g/kg of sea water.

Most of the existing monitoring systems are only focused on hardware or methods to determine the state of the ocean and no mechanisms have been developed to control water quality imbalances. Wireless Sensor Network (WSN) is one of the low costs and less manpower systems to monitor water features in remote areas [16,17]. It is widely used for monitoring water quality parameters such as turbidity, pH and chlorine residual which provides many advantages such as portability, real-time data acquisition and data logging capability [16,18]. Meanwhile, IoT applications in the monitoring system allow users to continue to get the results of water quality analysis in real-time. The results of data analysis can be accessed and displayed on user devices such as computers and smartphones. According to Nielsen [19], the use of smartphones or mobile devices in IoT applications can reduce energy consumption in terms of data generation, manufacturing and consumption costs.

Traditionally, monitoring is done by collecting and analyzing water samples physically. Only simple analysis without being influenced by factors such as concentration, size and shape of grains is one of the advantages of this method [20]. However, it is unsuitable for continuous data and long-term studies because of the difficulty in collecting water samples during unpredictable weather [21]. In this paper, we describe the design of a system that can be monitored water environment especially for coral and algae flourish. The proposed system is equipped with the embedded board involved is Arduino and several sensors to measure temperature, salinity and pH values as parameters. The system sent a notification if the condition exceeds the threshold value set which then alerts and an actuator mechanism will work to regulate back the condition. This system monitors remotely by using a network of sensors through an online platform. Thus, the data captured by the sensors sent to the system and actuate accordingly must be reliable to sustain the parameter sets in controlling the water quality. The rest of the paper is organized as follow. Section 2 presents the related works on aquatic monitoring system with various methods and parameters. Section 3 elaborates the system architecture, including the working principle, the algorithm and the system database. Section 4 concludes the proposed work with some future work lines.

2. Related Work

In the last decades, several methods have been developed to monitor or inspect aquatic life like coral reefs and algae, this includes using Autonomous Underwater Vehicles (AUV) [2, 22], remote sensing system [1, 23] and underwater sensors network [24]. A coral monitoring system particularly for the use of autonomous underwater vehicles (AUVs) has been developed [2] by using the ultraviolet LEDs and image analyses. In their system, the LabVIEW is developed using Google Maps and from the testing, consistent data and communication in the ocean condition has been successfully achieved. Moreover, the system also equipped with high quality of data logger monitoring, which able to measure the reading within short time. However, the system can only store 10 hours of monitoring data in the built-in memory card and only saves when the glider is launched. Belen et al. [24] invented a smart water quality monitoring system by using Raspberry Pi 3 Model B was used as the processing unit. The correlation between water quality parameters of aquaculture environment is discussed and as conclusion, the parameter characteristic from the experiment's changes with different water source. Furthermore, the system only focuses on two parameters: pH and temperature. The system does not cover the other parameters like salinity which is also crucial in coral reef and algae life. Similar study [25] designed a low-cost sensor system by using Arduino and Raspberry Pi 3B+ through LoRaWAN IoT Protocol. The system uses sensors, microcontrollers, and a web application for acquiring and monitoring data of six different water quality parameters.

Another low-cost water quality monitoring system which applies to a wide coverage has been successfully developed [26]. By utilizing the sensors network, the system can monitor the water quality parameters value precisely and use WSN and GSM technology to display the results. They used WSN due to its capability for real-time monitoring. As a result, the system shows great performance in reporting timely information. A study by [27] presents a portable model of a coral monitoring system consisting of a buoy mechanic, a controller unit, an underwater camera and a GSM modem. This system effectively captures the coral images continuously. Nonetheless the system is focused to image processing only. Meanwhile, Pérez et al. [28], focused on a Wireless Sensor Network (WSN) for coastal shallow monitoring in marine environment. The system consists of several sensors to monitor oceanographic parameters such as salinity and temperatures profile. However, no monitoring data was reported. In contrast, [22] developed an automatic collection system with deep learning modification (RetinaNet) and a network was used to identify and localize different coral species in images.

The application of big data analysis integrated with IoT for real-time monitoring of the great barrier reef has been studied [29]. Their studies include the application of IoT/WSNs on reefs to monitor aquatic parameters such as temperature profiles and weather data. On top of that, the system is able to detect Cyclone Hamish patterns using temperature, pressure and humidity sensors using IoT/WSN network architecture. Unfortunately, this study only reported the performance of the system and the implementation challenges from the deployed WSN.

Networks that operate in wireless domain have different characteristic with the wired domains. In wireless, they face variety of challenges including attacks and system faults. It is essential to understand the network behavior when exposed to challenges and their impact to the normal operation of IoT system [30]. The properties of a reliable network including redundancy for fault-tolerance and diversity for survivability to prevent network fail [31]. Using the mentioned strategy, it then is proposed to be adopted in many IoT-based smart monitoring system.

The main goal of this work is to provide a smart monitoring system that can be applied to aquatic system to maintain the water quality and lessen the operator task. Although a few research works have been done on aquatic monitoring, no system focused on investigation of optimum condition for coral reef and algae healthy growing has been proposed. Therefore, it is important to carry out the work of a monitoring system that can provide complete information about water quality parameters that can be analyzed as well as help in protecting and restoring the coral reef environment.

In this paper, we designed an IoT-based monitoring system Technically, the proposed system monitors the quality of water and records the data continuously with the help of IoT devices. The Wi-Fi module enables internet connectivity to send and transfer the measured data from sensors to the database. The contributions of the paper are as follows.

I. Architecture for aquatic monitoring system that considers multiple types of sensors and actuator mechanism to monitor water quality parameters.
II. An algorithm for measuring and storing data information in a database in a real-time scenario.
III. A system that used email to deliver a timely notification to designated person or system users.

3. System Architecture

The embedded systems applied in this work consisting of a microcontroller, three sensors, and an actuator connected via a network to a web server. There are three types of sensors are used in this work namely pH sensor, temperature sensor, and salinity sensor. The microcontroller acted as a data processor and sends real-time data from sensors to the web database using Wi-Fi as a connector. The block diagram of the proposed monitoring system is shown in Figure 1. Monitoring the parameters such as temperature, salinity, and pH is important to ensure the well-being of the coral reefs by maintaining an optimum condition by regulating any irregularities with an actuator. The data is very important especially when the condition exceeds the threshold point which results in an alarm notification to the targeted person. Immediate action can be taken to avoid unwanted or worsening of the condition. Importantly, the system works well to ensure that the data collected from the sensors reflect the true aquatic values and that the data sent must be timely. This is to ensure that information is delivered quickly and to enable an appropriate response to be taken immediately. for example, if the value of the monitored water quality parameter changes suddenly, the rapid transmission of information can provide sufficient time for the implementation of timely and timely action.

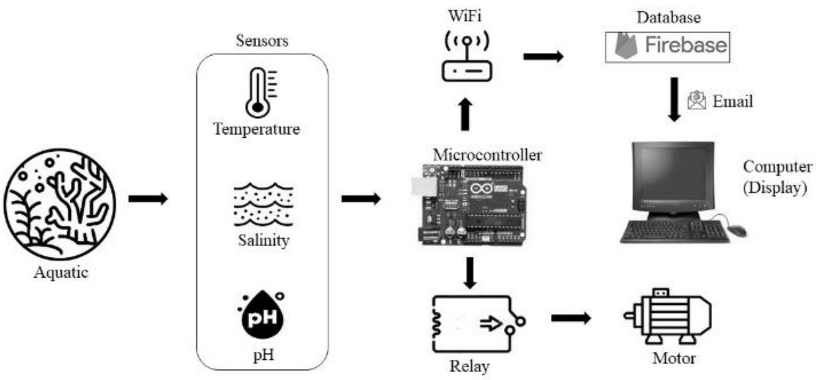

Fig. 1. System architecture for monitoring

As for the database system, Firebase is selected due to excellent functionality like databases, analytics, messaging and crash reporting. Firebase is built and scales automatically for Google infrastructure, even for the largest applications. Firebase products work well on their own but share data and insights and work together even better. The Firebase provides Cloud Storage, Realtime Database and Cloud Messaging function which is an important aspect of the proposed system. This is to store the data received from the sensors and send the data as message via the web server (email). The Firebase was created to unify all collected data and displays a real-time database (Figure 2) of aquatic parameters: temperature, pH and salinity condition.

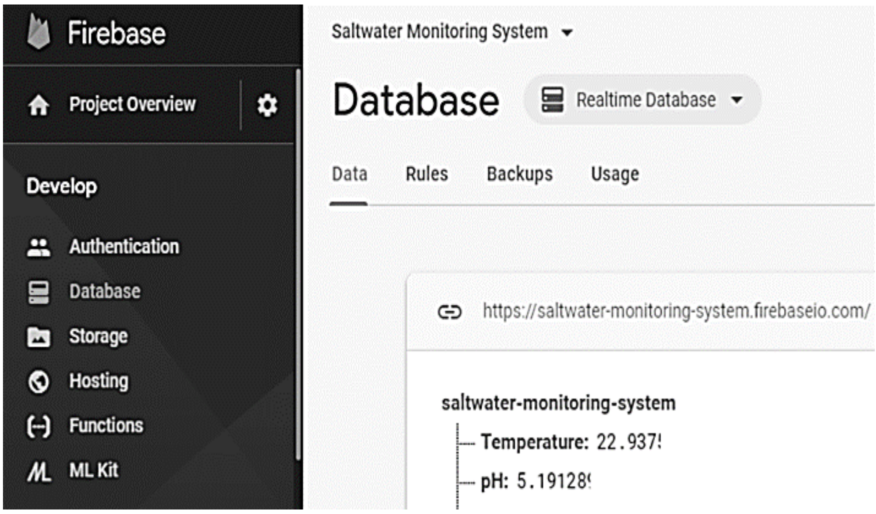

Fig. 2. Database display

The flowchart of system algorithm is shown in Figure 3. The system will detect the sensor after the board is connected to the power supply. Then, the sensor detects the parameters involved, namely pH, temperature and salinity and compares them with threshold values set in the program. The data from the real-time database is then pushed to a designated email. If the parameter value exceeds the threshold value, it will send a message and alert to the designated person. As for the pH value, it has an additional feature, where there is an actuator to regulate the desired pH if the threshold value is exceeded.

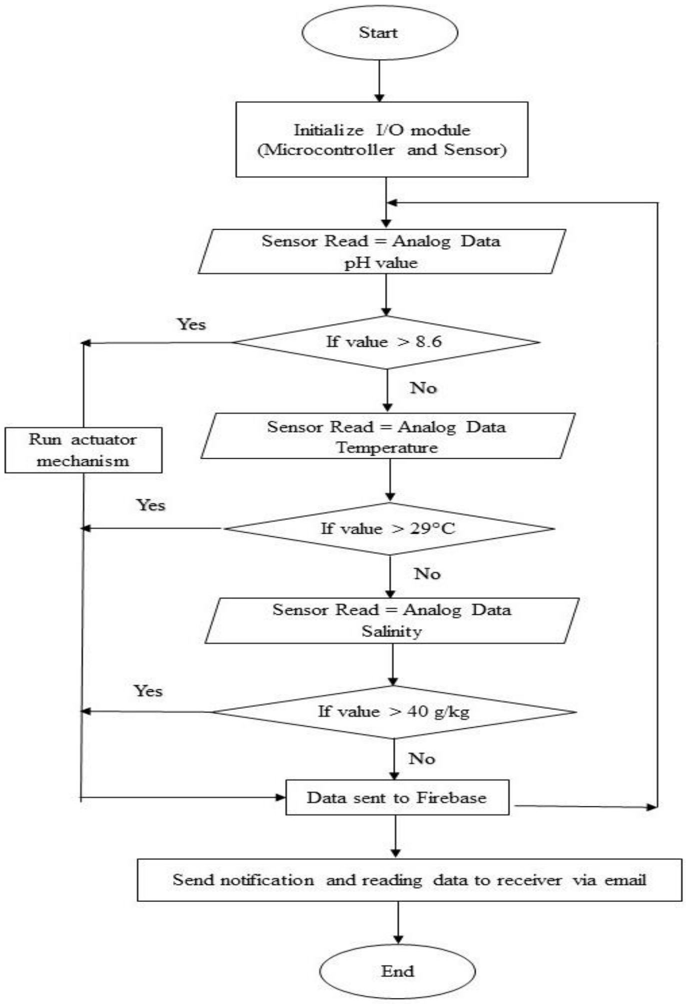

Fig. 3. System algorithm

4. Conclusion and Future Work

A proposed system for monitoring aquatic water quality has been described. The designed system enables remote data collection through online applications by integrating IoT. In future, monitoring systems will be designed with automatic corrective actions to monitor and maintain water quality parameters. Besides that, the system can be integrated with a 360˚ camera to capture images of coral reefs and algae, so that the data taken can be interpreted with pictorial support.

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