# REAL-TIME WATER QUALITY MONITORING OF AQUACULTURE POND USING WIRELESS SENSOR NETWORK AND INTERNET OF THINGS

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**ABSTRACT**

Data monitoring with updated information is important and necessary in today's era of digital technology. This study proposes a smart water quality monitoring (SWQM) system of aquaculture ponds that uses a Wireless Sensor Network (WSN) at a radio frequency band of 900 MHz in an Internet of Things (IoT) platform. The proposed system provides solution in the monitoring and death prevention of aquatic animals in culture ponds. The important parameters studied in this research are temperature, dissolved oxygen in water and potential Hydrogen (pH) values. The information monitored using the proposed SWQM device is transmitted to an operator through a cloud Internet platform via the router gateway. The operator can utilize the tracked information data on a smart device to achieve real-time monitoring. The data are analyzed and further evaluated on the basis of the results of water conditions. This implementation emphasizes the improvement of the agriculture process for the benefit of economic development at the community, society and national levels.

**Keywords:** *SWQM, WSN, IoT, Dissolved Oxygen, pH*

## 1. INTRODUCTION

In the era digital technology, media and innovation use for improving the quality of people's life is extremely necessary. Hence, data monitoring system based on wireless sensor networks (WSNs) and Internet of Things (IoT) are adopted in an increasing number of commercial

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solutions to implement real-time data monitoring and control system instead of human labour. Hence, these systems are useful in many different application areas. The field of agriculture is one of the most promising application areas of WSNs and IoT because of the agriculture productivity and prevent damage from various factors. The current work proposes a portable water quality monitoring (WQM) system based on WSN and IoT platforms. The proposed WQM system is designed to monitor the parameters of potential of hydrogen ion (pH), dissolved oxygen (DO), and temperature measurement. Moreover, the proposed WQM comprises a power management supplied by solar panels. The tracked information is transferred to users through an IoT-based system implementation by incorporating the wireless active RFID tag into WSN platform. The information is continuously allocated by incorporating wireless active radio frequency identification (RFID)-tags into the WSN platform. The information is continuously allocated by machine-to-machine (M2M) communication between the IoT gateway router Internetgateway and user's computers, including the online monitoring on mobile applications through the embedded circuit design on hardware and software sections.

The proposed WQM system related to multiple wireless technologies, which are RFID, WSN and IoT. Moreover, it is referred to as the smart real-time water quality monitoring system using IoT (SWQM-IoT) for flower crap farming, and other applications in aquaculture industries. The main challenge in ensuring a safe water supplying for aquaculture production is to minimize the effects of water quality issues by using an appropriate WQM mechanism. Generally, most aquaculture operators apply manual water quality inspection techniques. This conventional process requires a number of human operators to inspect the aquaculture ponds in wide areas. This requirement entails a high dependency on the skills of operators in performing manual water quality tracking. Thus, human error is highly likely operators are not consistently trained in performing manual water condition monitoring. In this regard, the proposed WQM is useful as it reduces the duration of manual data collection and the labour cost in hiring staff, and improves the aquaculture production by helping enrich aquatic animal health [1].

Nowadays, RFID systems are regarded as an effective automatic identification technology for object diversity. The most important functionality of RFID is tracking of locations and items [2, 3]. In the same way, WSNs have become an emerging platform of wireless technology, which is widely implemented in the WQM process. The proposed system uses active RFID tags that provide read and write functions, wide communication range and independent power supply. Furthermore, the proposed system is developed to realize a high signal strength and extend point-to-point communication distance to 100-200 m via collision avoidance techniques so as to ensure that communication is organized in a structured way and that all tags are utilized in the process [4]. However, RFID requires the use of WSNs, which connect the RFID end device to an RFID coordinator by implementing a radio frequency (RF) band of 900 MHz under the DigiMesh protocol, with a routing function; the RFID coordinator then provides the information to other coordinators [5].

Advances in IoT technology have led to significant progress in the application of environmental tele-monitoring. IoT has been applied to aquatic monitoring and wireless transmission by research institutes [6, 7] or environment departments [8] and so on.

This work presents a concept for the design and development of a rapidly deployable WSN and IoT platform for the water quality tele-monitoring of smart aquaculture in shrimp farms. The proposed automated SWQM-IoT system is an efficient innovation for shrimp farming that can improve the economic status of entrepreneurs. It can also improve a country's economic growth by boosting the aquaculture industry.

## 2. METHODOLOGY

The proposed innovation relates several methodologies which are outlined as follows. The proposed SWQM system comprising a mesh wireless sensor system is developed using multiple wireless technologies including an RFID system, a WSN-cloud database access through, mobile application and an IoT system platform. The DigiMesh protocol selected in this work is less complex than IEEE 802.15.4 ZigBee protocol and thus allows rapid configuration in its nodes. These monitoring end devices can be configured as a one role in the same WSN and they can intelligently find their own radio path to transmit information to the proposed IoT gateway [4]. The structure of the WQM system is shown in Figure 1.

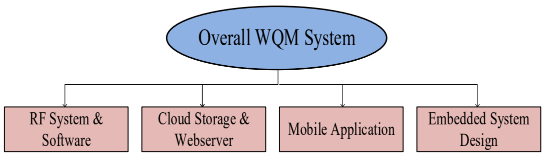



*Figure 1: Overall Frameworks of Smart WQS System*

Figure 1 presents the overall SWQS-IoT system, which consists of the following components: 1) RF system and software, -2) cloud storage and webserver, -3) mobile application and 4) embedded system design. The contents are explained in two main sub-sections discussing the embedded RF system. The proposed embedded WQM comprises RF system and software, and features an embedded programming design. Further details are provided herein.

### 2.1 Proposed Embedded Multiple Sensors and RF System

The proposed end monitoring node comprises multiple related components. The embedded SWQM-IoT device and wireless mesh sensor network can enable RFID systems to work in multiple hops to broaden the communication distance range of readers through an RF transceiver and microcontroller that coordinate different component in each node. Each embedded SWQM node can transmit its unique ID number and the details of its sensed data to all other nodes through the wireless network system in the 900 MHz. The SWQM-IoT gateway listens to the RFID coordinator radio of neighbouring nodes. Whenever a channel activity is discovered, a tag awakens its sensor device to listen to the channel and then receive data through the DigiMesh protocol of the WSN. Meanwhile, other SWQM-IoT nodes can remain in sleeping status whilst consuming ultra-low power during its operation. K.H. Kamaludin and W. Ismail shown that an IoT node can achieve power consumption lower than 0.4 W during sleep mode [9]. This ultra-low power consumption feature greatly enhances the operation period and minimises maintenance work. The block diagram of the proposed SWQM is shown in Figure 2.

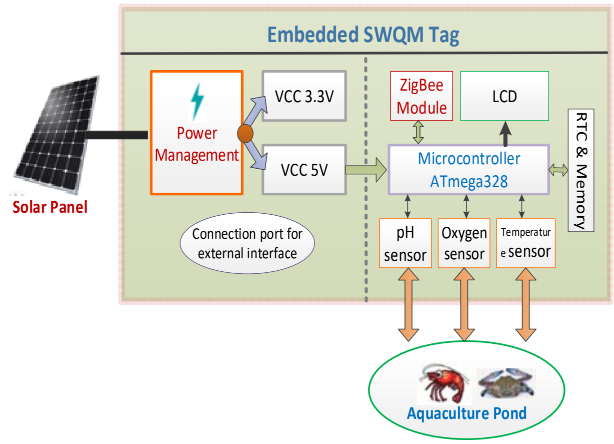



*Figure 2: Proposed Block Diagram of WQM Architecture Design*

Figure 2 presents the block diagram of the front ends of the proposed SWQM end device in which the embedded microcontroller is designed on the basis of the Arduino Uno schematic circuit [10]. The coordinator transceiver designed on the basis of the WEMOS WIFI ESP8266 Arduino board [11] is embedded with embedded ZigBee-Pro and WiFi modules to become an Internetgateway. The SWQM end devices are embedded nodes with active RFID tags (ZigBee) to collect information including the pH value, DO and water temperature of aquaculture pond during the monitoring process. The Wireless ZigBee-Pro module acts as a coordinator that receives the captured data from sensor nodes through the WSN platform [12].

The physical water quality sensors are the sensing nodes contains and the signal conditioning circuits required to interface with the measurement nodes. A water quality sensing node consists of a microcontroller that processes raw sensing information and then transmits all information to a wireless coordinator node. The wireless coordinator and sensing end device make up the wireless node, the information they receive is sent to the host station and smart devices for the real-time monitoring of the water quality. Water quality sensors are detailed as follows.

- Temperature sensor: A temperature sensor is an important component prototype. It is used to measure water temperature of the water, and it comes in various types, including thermocouples, thermistors or a solid state temperature sensors. The waterproof DS18B20 temperature sensor is adopted in this project because of its good control and design capabilities. This probe uses the original DS18B20 temperature sensor chip. It is waterproof, and resistant to moisture and rust because its encapsulation in a high-quality stainless steel tube. Thermistors are generally used for applications below 300 °C. They are generally resistors with temperature dependent resistance and given their resistive nature, an excitation source needed to read the voltage across terminals [13]. Herein, the temperature ranges between of 10 °C to 40 °C is considered. Thus, the measured voltage is proportional to the temperature with either a negative temperature coefficient (NTC) or a positive temperature coefficient (PTC). This correlation is not linear, especially for large temperature regions, but it can be compensated for with the Steinhart-Hart equation. Thermistors are inexpensive and widely used in many applications due to their small size and reasonable accuracy.

- DO refers to the amount of oxygen ($O^2$) dissolved in water and indicates the health of the water ecosystem. Oxygen is vital to all forms of life, including aquatic life. DO is used by plants and animals for respiration and by aerobic bacteria in the process of decomposition. It can be in the range of 0-18 parts per million (ppm), but most natural water systems require only 5-6 ppm to support a diverse population. In the prototype presented herein, the DO kit-ATLAS SCIENTIFIC is used. It is a perfect calibration equipment for hydroponics and standard lab use. Moreover, it offers the highest level of stability and accuracy through its compact D.O. monitoring system.
- The pH sensor measures the level of acids and bases in water and is used in environmental monitoring. pH range from 0-14 and each increment represents a 10-fold change in pH value. In this study, the pH monitoring of seawater in an aquatic pond. Different organisms thrive in varying ranges of pH, and the smallest change in pH can adversely affect them.

The implementation shows the general building blocks of a smart wireless real-time monitoring system. The following aspects are mainly monitored:

- Power management: Recently, The global energy crisis has become increasingly serious and continuous to greatly affect our lives. Therefore, many researchers have paid close attention to the interesting and challenging problem of energy life time [13]. The proposed SWQM architecture system was designed and contributed the energy source supplied from battery of 12V, 7.2AH, which was collected through the power resource from a solar panel with individual power management for 3.3 V and 5.0 V to maintain end modules stability. Therefore, the battery lifetime problem is solved with the proposed embedded SWQM concept.
- The wireless data collection subsystem consists of multi-parameters sensors and an optional wireless communication device to transmit sensor information to a controller. The controller gathers the data and processes the data at the same time.
- Wireless data transmission consists of a wireless ZigBee-Pro communication device with built in security features, such as advanced encryption standard (AES). This device transmits sensed data from a controller to data cloud storage. Information pertaining to pH, oxygen, and temperature is relayed wirelessly to a notification node. Herein, a wireless transceiver (i.e. XBee-Pro module) is purchased off-the-shelf. Other wireless communication protocols include Bluetooth, BLE and ZigBee [13]. WiFi is based on the IEEE 802.11 specification and has a high data rate with long range capabilities (up to 100 m), but its power consumption is relatively high. ZigBee-Pro can achieve ling-of-sight (LOS) communication range of up to 6,500 m [9].

### 2.2 Cloud Storage and Webserver

The contribution of this work is involved with IoT front end, which can communicate with the data cloud through Internet connection via a router Internet gateway device. The proposed SWQM specifications are established on the basis of the main component qualifications and features within the research framework as shown in Figure 3.

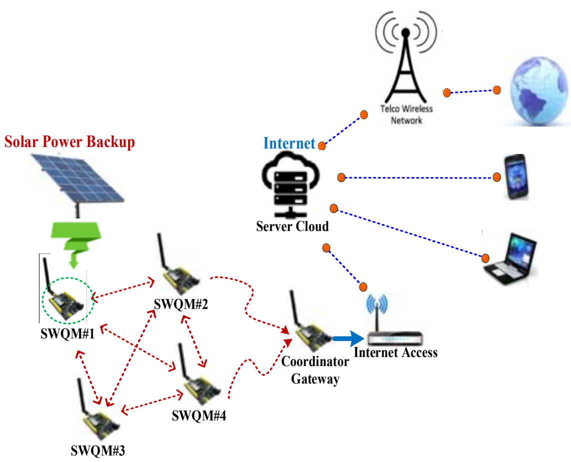
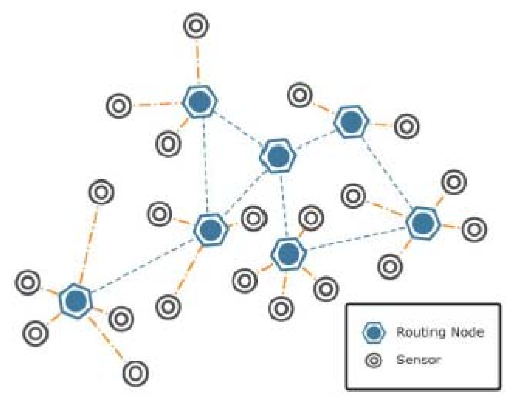



*Figure 3: Proposed SWQM Network System for Smart Farming*

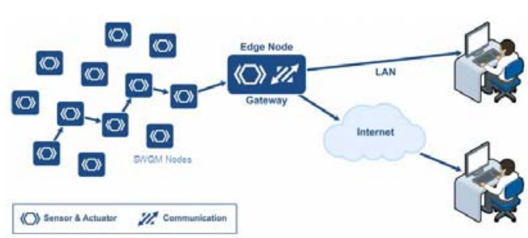
The SWQM node attempts to discover its path in the WSN. Once it identifies this path, it relays the captured sensor data to other nodes, which also serve as routers until the data reached the coordinator gateway. At this stage, the received packages are transmitted from the RF protocol into the TCP-IP protocol by a gateway microcontroller. The small amount of text data (a few bytes) pushed into the cloud database through the available Internet coverage and can be stored permanently without the need for a major database housekeeping activity, such as that required in picture and video storage. The innovation of the SWQM system is that real-time data can be assessed from the cloud database through a mobile device as a complete IoT solution.

Several sensors are available to monitor water quality parameters. These sensors are placed in the water to be tested which can be either stored water or running water. Thus, water quality sensors convert the physical parameter into equivalent measurable electrical quantity, which is given as input to controllers through an optional wireless communication device. The main function of the controller is to read the data from the sensor, optionally process it, and send the same to the application by using appropriate communication technology. Choice of the communication technology and parameters to be monitored depends on the requirement of the application. Moreover, the application includes the data management functions, data analysis and alert system based on the monitored parameters.

In this study, the SWQMs are sensor nodes to monitor the water quality in the aquaculture pond, and transmit data to the user through IoT platform. SWQMs necessary to have gateway sensor nodes to connect to the internet. This gateway will connect to the Internet network, which all devices in the network and all sensor nodes can send data to the internet.




*(a) SWQM node communication as wireless sensor network*




*(b) SWQM nodes linked with internet through gateway*

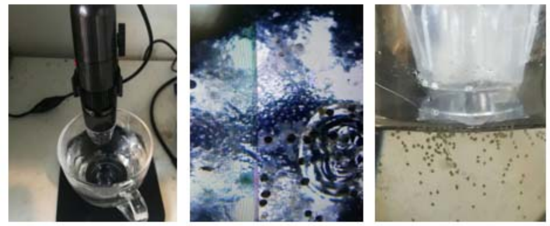
*Fig. 4. SWQM communication system and IoT application*

The gateway is under the local network, which further determines whether or not it is allowed to connect to the Internet or to the local network.

## 3. THE EXPERIMENTAL RESULTS AND DISCUSSIONS

This paper presents the design and development of a rapidly deployable real-time WQM system that uses WSM and IoT platforms. This system is designed for the tele-monitoring of surface water, including its quality characteristics. The proposed framework should be easily and rapidly deployable, and its maintenance should be simple. It may be deployed in the field only in the short-term, but it can still achieve high-resolution spatiotemporal sampling. The data collected this approach can benefit aquatic environmental monitoring in term of various parameters such as the survey of an unknown area for collecting useful knowledge to establish an environmental model, the design of a sensor deployment strategy for long-duration monitoring, an analysis of micro-aquatic environmental changes, and so on. In the present work, the efficient monitoring planning and the effective online water quality index are proposed and embedded into the developed platform.

The quality of water is monitored on the basis of its physical, chemical and biological parameters. With the objective of providing an overall representation of the water quality based on all measurements, much effort has been exerted toward developing water quality indices [14]. The proposed SWQM system provides a convenient way to represent water quality by aggregating the measured data of water quality parameters into numerical scores. These scores are then verified and categorized for reporting to the host station, thereby benefitting technicians, farm owners, and other users. It is aimed at strengthening the agricultural and economic sectors of communities. Moreover, it is applied off-line by using the data collected at low sampling rates via automated sampling. The SWQM prototype was tested through an experiment involving the water quality in the Ban Hua Khao Crab Culture Centre, Songkhla, Thailand, The results are analyzed to evaluate the advantages and disadvantages of the prototype and thereby facilitate its automatic execution.



*(a) Microscope (b) Baby crab in a zoea stage*

*Figure 5: Testing SWQM Prototype for Aquaculture Crab Pond*

Figure 5 shows the water samples obtained from a crab pond. The life cycle of flower crab lasts for 31-49 days and involves seven larval stages. Even in the early stage, crabs have hard hard outer shell (oxoskeleton). In order to grow and move to the next stage, the larva must moult, that is, it must shed or cast off its shell. During moulting, the exoskeleton spits, and a soft-bodied larva comes out. The animal remains soft for a short while, and then swells up by absorbing water. Then minerals from the seawater (especially calcium) harden the outer covering to form a new exoskeleton. When the larva loses the extra water, it shrinks but a space is left within the exoskeleton for growth [15]. The zoea stage is important in maintaining and growing baby crabs. Thus, the aforementioned parameters are considered herein by using the proposed SWQM for data collection from multiple ponds. The information is sent to users via the WSN and IoT platform.

### 3.1 Parameters Tested in Aquaculture Pond

The parameters tested in the aquaculture pond, include temperature, oxygen and pH values. The results were sampled for 10 times in the period of approximately 10.30 am on the 26th of June, 2019 at Sonkghla Province, Thailand. All the parameters considered in the experimental results are explained as follows.

1) The temperature of water is an important variable in aquaculture. It is affected by many factors that connot be controlled and depends upon the amount of solar radiation, air temperature, or the temperature of the water passing through the culture unit. Temperature strongly affects the growth and survival of aquatic animal organisms [15].

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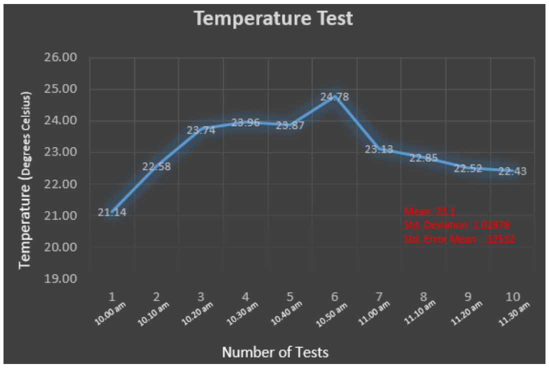


*Figure 6: Temperature Test Results*

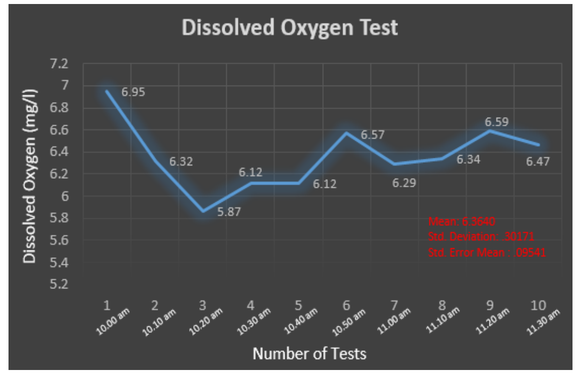


*Figure 7: Dissolved Oxygen Test Results*

The temperature test results are shown in Figure 6. The experimental assays are measured for 10 times between 10.00 AM to 11.30 AM. The average temperature is taken in each time period and plotted in a graph. Therefore, the total average of the temperature measurement is 23.1 °C, standard deviation is 1.02876 and standard error mean is .32532. The various temperature fluctuation and reference mean temperature value (23.1 °C) are significantly different at 95% reliability.

2) DO is a measurement of how much oxygen is dissolved in the water, that is the level of free, non-compound oxygen. It is an important parameter in assessing water quality due to its influence on the organisms living within bodies of water. Figure 7 shows the fluctuation of the DO values between 10.00 AM to 11.30 AM. The average of DO value is 5.87 mg/L. The changes in the DO values in an aquaculture pond depend on several factors. Rapidly moving water tends to contain a large amount of DO, whereas stagnant water contain low amount of DO. Bacteria in water can consume oxygen as organic matter decays. Thus, excess organic material in lakes and rivers can cause eutrophic conditions, which are characterised as deficient of oxygen and can cause a water body to 'die'. Aquatic life cannot survive in stagnant water that contains large amounts of rotting, organic material. Especially in summer, the concentration of DO is inversely related to water temperature.

3) pH: The pH detection level is a water quality measurement, which indicates whether water is acidic or alkaline. More precisely, pH indicates the hydrogen ion concentration in water and is defined as the negative logarithm of the molar hydrogen ion concentration (-log [H+1]). Water is considered acidic when pH is below 7 and basic when pH is above 7. Most pH values encountered fall within the range of 0 to 14. The recommended pH range for aquaculture is 6.5-9.0. The results shown in Figure 8 indicate the fluctuation of the pH values in the ranges of 5.12-6.02. In this condition test, the blood of aquatic animals in the culture pond comes into close contact with water, which thus provides a suitable conditions for aquaculture. The pond pH varies throughout the day due to respiration and photosynthesis.

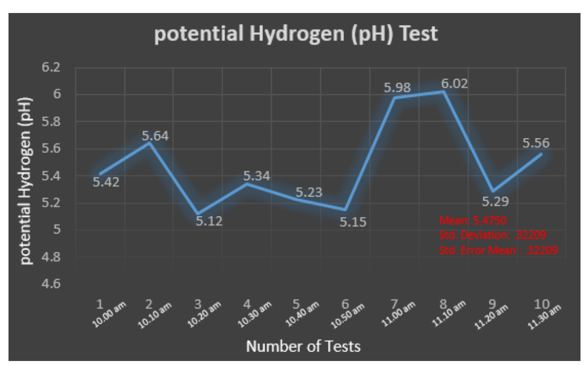


*Figure 8: pH Test Results*

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The graph in the Figure 9 compares three parameters, which are temperature, $O_2$, and pH values. These parameters are compared to analyse their relationship. The temperature and DO values show an inverse relationship. That is, an aquaculture pond's temperature varies throughout the day due to respiration and photosynthesis. Figure 10 (a) shows the relationship between temperature and DO values and (b) the relationship between temperature and pH values.

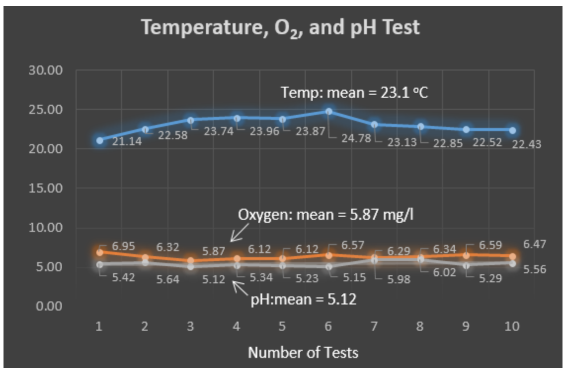
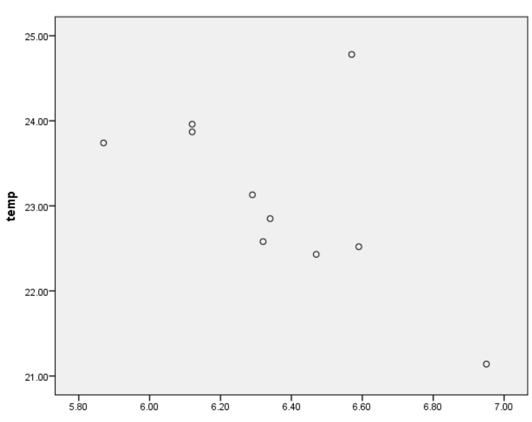
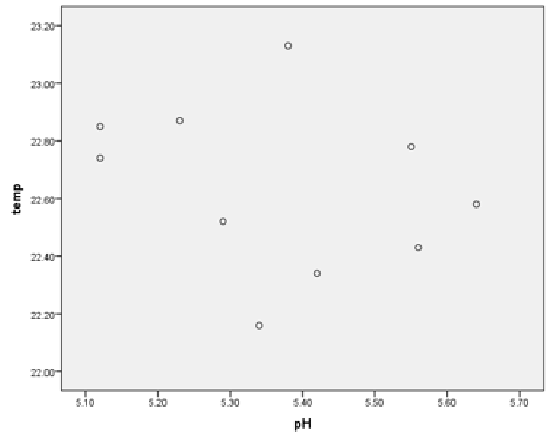



*Figure 9: Relationship between Temperature, Dissolved Oxygen, and pH Tests*

The results reveal that the temperature parameter affects the DO and pH values in an aquaculture pond. When the temperature is high, the DO and pH values decline, these variables are negatively related according to the graph shown in Figure 10.




*(a) Temperature versus Dissolved Oxygen*




*(b) Temperature versus Water's pH in the Pond*

*Figure 10: Relationship between Temperature, Dissolved Oxygen, and pH Values in the Aquaculture Pond*

On the basis of the rest results, the three parameters are analyzed by the Pearson correlation statistic (Figure 11). The statistical analysis results indicate that the temperature and DO values have an analysis value of .641*, which means that the relationship between them is at a moderate level and that they are in a consistent direction. Meanwhile, the temperature and pH values have an analysis value of -.269, which means that the relationship between them is at a low level and is a negative.

**Correlations**

| | | temp | oxygen |
|---|---|---|---|
| temp | Pearson Correlation | 1 | .641* |
| | Sig. (2-tailed) | | .046 |
| | N | 10 | 10 |
| oxygen | Pearson Correlation | .641* | 1 |
| | Sig. (2-tailed) | .046 | |
| | N | 10 | 10 |

*. Correlation is significant at the 0.05 level (2-tailed).

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Correlations

| | | temp | pH |
|---|---|---|---|
| temp | Pearson Correlation | 1 | -.269 |
| | Sig. (2-tailed) | | .452 |
| | N | 10 | 10 |
| pH | Pearson Correlation | -.269 | 1 |
| | Sig. (2-tailed) | .452 | |
| | N | 10 | 10 |

*Figure 11: Relationship between Temperature, Dissolved Oxygen, pH Values in Aquaculture Pond Using Pearson Correlation Statistic*

The experiment results may not be highly consistent with the theory [17]. This variation could be attributed to the short time period of sampling in the experiment. The graphs in Figure 6 and 7 indicate that the two parameters are clearly inconsistent with the theory.

## 4. CONCLUSION AND FUTURE WORK

As the water quality monitoring of aquaculture pond based embedded system on WSN integrated with IoT innovation is responding to the requirements of smart people in modern era. The proposed project carries facilitate and solve the current problems of people in daily life. In this article brings along the useful of data monitoring and IoT for main priority to collect, store, transfer, and data analysis to the user. The implementation supports the improvement and development of agriculture quality for communities, society and the country as a whole regarding to solve the deadly problem of aquatic animals in the pond in a timely. The results of this experiment can provide guidelines to aquaculture operators and researchers for alternatives in aquaculture monitoring.

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