Implementing Zigbee-based Wireless Sensor Network in the Design of Water Quality Monitoring System

Daniel D. Dasig, Jr.

Abstract**: *This study presents the design and development of a precision fishing technology utilized in water quality monitoring with phytoremediation system using a Zigbee-based Wireless Sensor Network. The system afforded a real-time water quality monitoring using multiple sensors spatially deployed. The sensor node implemented in the Wireless Sensor Network to perform data sensing utilities with the water quality parameters including the water temperature, pH level, water dissolved oxygen and the water level during high-tide and low-tide. During the development, a P89V51RD2 microcontroller, ZigBee module with IEEE 802.15.4 standard, and radio frequency (RF) transceiver were utilized. The developed precision fishing technology utilized the Internet of Things architecture. The IoT device layer includes the temperature sensor, pH sensor, dissolved oxygen sensor, and the water level sensor. Phytoremediation was also used as an alternative solution for soil and water remediation. Further studies using recent and advanced remote sensing technologies and IoT-based solutions can be developed to address issues in the primary sector of the economy.***

Keywords : Smart IoT, Zigbee, wireless sensor network, phytoremediation

I. INTRODUCTION

Aquaculture has been considered as one of the push factors to an emerging economy [1,2] and cash flows to emerging markets [2]. It also drives potential contribution to an increase in food production. Aquaculture is aquafarming of marine entities including fish, crustaceans (shellfish), algae and other marine plants. A fish farmer or pisciculturist cultivates freshwater or saltwater populations using a controlled setting such as fish ponds enclosure [3]. The impetus and rudiments of aquaculture have gained an expedient approach in the production of seafood to countervail the demand and strains on natural populations.

According to the 2011 data, the world productivity in terms of aquaculture in the year 2010 had reached to at least 62.7 million tons, 6.2% higher than the Global Aquaculture Production Statistics [4]. However, because of the extent of demand for aquaculture or marine produced as a source of protein [5] and world fish supplies [7], it has even imposed fish farmers and fishery managers to inbreed innovative techniques in the husbandry of the fish [4,5,6]. In order to meet the peremptory and demands, pisciculturists and fishery managers should venture in extensive aquaculture in fiords, estuary, man-made lakes, bays, rivers or ponds [5,6].

Notwithstanding, the scale of aquaculture buildout in most agricultural countries in the world has caused environmental distress [6,7] to the freshwater and marine ecosystems, and to the fishing industry [7,8], one of the largest the market sectors in the world. Fishery managers should account the two-way interfaces of marine or aquaculture and the environment [11], intensive pond bottom soil, sediments and design [12,13], and ecologically sound management practices [7].The global prominence of aquaculture production has changed the fish food dynamics in the aquaculture economies [8,9] by providing more fish that capture fisheries [10,11], however, its economic value diminished because of infectious diseases [9].

Due to oxygen depletion, some 250 metric tons of bangus (*milkfish*) in fish pens were lost to a fish kill in Obando, Bulacan, Philippines in May 2018 [14,15]. Based on the actual damage assessment report of the Bureau of Fisheries and Aquatic Resources (BFAR) Region 3, and the Department of Agriculture, at least P29 million worth of fish kill to a 130 hectares of fishpond due to a 34 °C temperature which coincided with low tide level at 0.050 meters [15, 20]. Another fish kill in the littoral waters of Bolinao, Pangasinan, Philippines were recorded in 2002 due to algal bloom [16,19], high total dissolved inorganic nitrogen (0.31–24.2 μM) and dissolved phosphate (0.09–4.47 μM) [22].

In March 2005, another recorded coastal water changes by discolourization in the west coast of Puerto Princesa, Palawan, Philippines [17,21]. In the study of [18], it was posited that the fish kills of milkfish and tilapia was due to the effect of the corrosive compound and sulfide tolerance. Also, fish kills are likely to recur when the aquafarm has a high organic load, no aeration, and limited water circulation and water exchange [17,18]. The government agencies have invigorated sound management and practices in aquafarms, there was the recurrence of *Cochlodinium polykrikoides*. To countervail some of these issues, a study on biogeochemical settings in residues augmented by biological substance [23] was conducted, and cage mariculture of groupers (*Epinephelinae*) has been encouraged to be practised [24] in order to prevent fish kills phenomena.

This study presents the design and development of a precision fishing technology utilized in water quality monitoring with phytoremediation system using a Zigbee-based Wireless Sensor Network (WSN). The focus of this study was to provide real-time water quality monitoring using multiple sensors spatially deployed using Wireless Sensor Network.

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Dr. Daniel D. Dasig, Jr., Graduate Studies, College of Science and Computer Studies, De La Salle University- Dasmarinas, Dasmarinas City, Philippines. Email: dhuniel2006@yahoo.com, dddasig@dlsud.edu.ph

II. BACKGROUND OF THE STUDY

A. Water Quality Monitoring and Control

To an increasing extent, aquaculture is accounted as an inherent vehicle for fish food production and supply for global food security. It was emphasized in the study [25] that the efficient and desirable aquaculture production heavily relies on the bodily (physical), biological, and the chemical qualities of water [26], and suitable environment in which they can reproduce and grow [27]. The onslaught of the 4th Industrial Revolution (4IR) or the cyber-physical systems, the vast majority of fish food productions have embarked towards automation [28]. The water quality can be characterized by the following parameters; water temperature, pH level, its dissolved oxygen presence, ammonia, nitrates presence, the water salinity, and water alkalinity [26], water limpidity (or how transparent the water is), turbidity (haziness or cloudiness), water color, carbon dioxide (to produce carbonic acid), hardness (magnesium and calcium being dissolved), nitrites content, primary productivity, and contents of Biochemical Oxygen Demand (BOD). [27, 28]. Fundamentally, water temperature hampers fish feeding patterns and growth [31].

Temperature fluctuation can chronically create environmental turbulence, stress and disease breakout [30, 31]. Higher temperature or warm water in the ponds constrains a lesser amount of dissolved oxygen. The work of [29] has realized the water treatment processes by reducing the content of inorganic nitrogen and of organic matter in intensive aquaculture [30]. Researches findings suggest that the extent of dissolved oxygen (DO) present in water surges as water temperature shrinkages, and DO shrinkages whenever the salinity surges [31]. In this design, the water quality constraints understudy includes water temperature, pH level, dissolved oxygen presence, and the water level. The multiple sensors (Sensor Nodes) were used to gather and accumulate the water quality sensing data, and the data gathered are transmitted to the Central Station (Base) using the Zigbee (IEEE 802.15.4) standard with the XBee Module at a transmission distance to 10–100 meters line-of-sight.

B. The Wireless Sensor Network (WSN) and Zigbee

Wireless sensor network (WSN) has rapidly proliferated in several applications because of its salient features. Wireless sensor network is a spatially distributed with a dedicated remote sensing capability for environmental scanning, monitoring and capturing the real-time conditions, and thereby sending it to the Central Station. In the onslaught of cyber-physical era, and the recent ramifications in the telecommunication and wireless communication, WSN has been extensively casted off in many industrial applications for environment monitoring, tracing and tracking, and employed as enabling the tool to deploy intelligent and low-cost systems [32].

The underlying feature-rich WSN has remained serviceable by means of micro-electro-mechanical technologies [33], at such WSN localization [34], and application in the areas of digital electronics and wireless communications [32,33]. Wireless Sensor Network was used by [35] to develop an aquaculture monitoring while [36] has deployed a system to measure continuously the water quality in aquaculture built with the IEEE 802.15.4 standards and ZigBee. The system of [37] utilized a ZigBee wireless sensor network to monitor a probing aquaculture recirculating system. ZigBee was accounted as the most appropriate and commonly used for WSN due to its salient features and applicability in the remote sensing, automation and control, embedded system applications, and industrial system development [36, 37, 38].

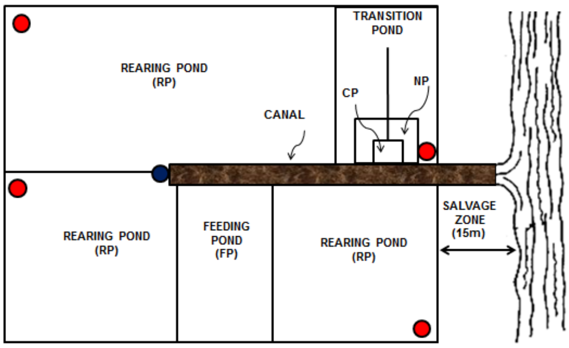

Fig. 1 The Fishpond Layout and Wireless Sensor Network[51]

Fig. 1 presents the layout of fishpond with sensors deployed. Sensor Node 1 includes the water temperature sensor, a pH level sensor, and the dissolved oxygen (DO) sensor- in red bubbles. Sensor Node 2 is composed of water level for high-tide and low-tide measurements- in a blue bubble. The modified design taken from [51] consists of four sets of sensor nodes 1, and 1 set of sensor node 2. The pond or pool was segmented into Rearing Pool/Pond (RP), Transition Pool (TP), Catching Pool/Pond (CP), Feeding Pool/Pond (FP), and Nursery Pool/Pond (NP). These segmented parts of the pond are vital to the operational activity, good water quality supply and tidal fluctuations management.

C. Phytoremediation

This study also pegged to conduct water and soil analyses using phytoremediation. Fish kills recurrences were attributed to the sediments, temperature, sulfide, and other water quality parameters which were related to contaminations of soil and water. In this study, Phytoremediation was utilized to conduct environmental clean-up using floating and submerged plants and their associated microbes [39, 40] to remediate contaminated water and soil [41, 42].

Because of waste disposal and industrial activities around coastal areas, there were increasing sewage sludge and soil acidification and metal toxicity [43]. Heavy metals in water include mercury (Hg), copper (Cu), cadmium (Cd), thallium (Tl), arsenic (As), manganese, iron (Fe), chromium (Cr), zinc (Zn), and lead (Pb) which causes the direct and indirect effect to fish in the ponds [43,44]. Phytoremediation has been proven to be cost-effective and noninvasive alternative technology to reduce and remove heavy metals from water and soil [40,41].

III. THE SYSTEM DESIGN

This section presents the system design and components as part of system configuration consisting a Sensor Unit Wireless Sensor Node, and Central Monitoring Station (CSM).

A. Sensor Unit

In this design, the Sensor Unit is composed of water temperature sensor, pH level sensor, dissolved oxygen (DO) sensor, and the water level sensor. In measuring the water temperature, a thermometer sensing technology was used, and a glass electrode method was utilized for pH value. On the other hand, a membrane electrode technique was utilized for a dissolved oxygen sensor and a localized sensor designed out of an operational amplifier as a functional water level sensor. Figure 2 depicts the illustrative design of the Sensor Unit (enclosed in the dotted-line).

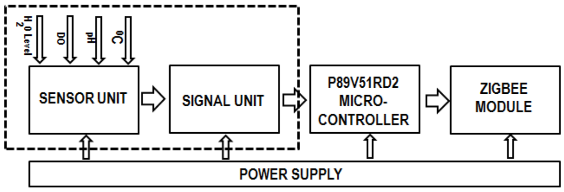

Fig. 2 Block Diagram of Sensor Unit of the system

Operationally, this unit utilizes a 5VDC power supply. The sensors collect the water quality data based on the parameter it was intended. The temperature sensor captures the water temperature, and the pH sensor captures the acidity or basicity of water (if the water is still conducive to fish life) or the concentration of carbon dioxide. The dissolved oxygen (DO) sensor gathers the pond's DO information, and the water level sensor to measure the amount of water in the controlled fish enclosure or fishpond. These sensors convert data gathered into electrical signals and are transmitted to the signal unit which is connected to a P89V51RD2 microcontroller.

B. Wireless Sensor Node and the System

Another module in this design is the Wireless sensor node. The Wireless Sensor Network is the collection of sensors, a sensor node or sensor unit as depicted in Figure 1. In this design, there are four (4) sensor nodes in the WSN reflected as small red circles spatially deployed in the fishpond.

As illustrated in Figure 1, the system composed of sensor unit, signal unit, microcontroller, ZigBee module, and radio frequency transceiver for communications at the physical layer. The developer utilized P89V51RD2 as the microcontroller to implement an embedded system. The microcontroller used is an 80C51 microcontroller with 64 kB Flash; its RAM has 1024 bytes, with flexibility for an X2 mode option. The Zigbee module (IEEE 802.15.4) standard and is a low-rate wireless personal area network (LR-WPANs) was utilized since it facilitates a two-way communication between sensors and control system.

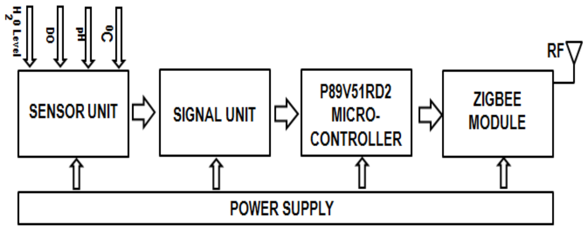

Fig. 3 The Block Diagram of the System

C. Central Monitoring Station (CSM)

The Central Monitoring System (CSM) is the web-based application which provides real-time visualization of the water quality measurements [51, 52]. The graphical user interface (GUI) has four sub-components including the temperature in (0C), pH or water acidity in moles per liter, dissolved oxygen in milligrams per liter (mg/L), and water level measurements (ft).

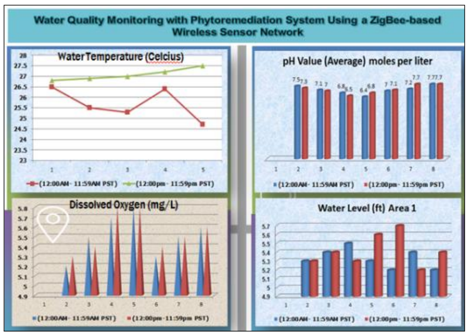

Fig. 4 The Graphical User Interface (GUI) Online Water Quality Monitoring System

The CSM also includes gadgets such as world clock and calendar. The web app was developed using PHP & MySQL, and http shield. The CSM web application is composed of system modules including Login, File Maintenance, Transaction and Reporting, Back-up and Recovery, Configuration Management, and the Dashboard. Fig 4 depicts the CSM Dashboard as a visualization tool (summarized records) for the fishery managers and pisciculturists. The system refreshed every 20 seconds and the dashboard graphs and charts changes when there have been changes on the data collected by the sensors.

IV. RESULTS AND DISCUSSION

On the basis of system testing and results, the following sub-sections are presented. The water quality constraints considered in this study include the water temperature, pH level, dissolved oxygen (DO0, and the water level in the fishpond during high and low-tide. Before the system was tested in a controlled fishpond, the researcher conducted the prototype testing.

During the prototyping stage, the system was integrated with the phytoremediation System implemented in aquaponics in a mid-sized 25-gallon aquarium tank of 24"x12"x20", with a filled weight of 282 lbs. The researcher utilized artificial soil made up of sand and perlite and vermiculite with White Spotted Grouper (*Epinephelus coeruleopunctatus*), Nile tilapia (*Oreochromis niloticus),* and other vivarium aquatic animals irrigated and pumped with freshwater. Freshwater pumped to the system contains chemical elements such as lead, zinc, cadmium and copper.

A phytoremediation using rhizofiltration was used to reduce and remove heavy metals from the system using floating and submerged aqua plants.

Thereafter, the system was piloted in a 50m x 40m controlled fishpond in Obando, Bulacan from January 24-30, 2019. The controlled fish enclosure nile tilapia *(Oreochromis niloticus),* bangus (milkfish) and white spotted grouper *(Epinephelus coeruleopunctatus)*. The results of the gathered data from the testing are reflected in Tables I-IV.

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A. Temperature Measurement

Water temperature is an important parameter to be considered by fishery managers and pisciculturists. It is the degree or extent of hotness or coldness in the ecosystem.

TABLE- I: The Average Water Temperature (C^0)

Dates	Average Water Temperature (Celsius)	
January	***(12:00AM- 11:59AM) PHT***	***(12:00pm- 11:59pm) PHT***
24	26.5	26.8
25	25.5	26.9
26	25.3	27
27	26.4	27.2
28	24.7	27.5
29	25.5	26.8

In the aquaculture, the nile tilapia *(Oreochromis niloticus)* can be fully cultured around 34 weeks, and bangus *(milkfish)* and white spotted grouper (*Epinephelus coeruleopunctatus) with* a tolerable water temperature threshold of 25 ^oC to 30 ^oC [45]. Table 1 depicts the average water temperature of the fishpond from January 24-30, 2019. It can glean that the lowest water temperature is 24.7 ^oC and the highest is 27.5 ^oC. During this testing, water surface and the actual lowest and highest temperature based on the weather bureau PAGASA was 23 ^oC and 30 ^oC, respectively. The system provides alerts and notification to the system user when the temperature is higher than 30 ^oC, hence, they can conduct remedies, such as water exchange and mechanical aeration.

B. The pH Level Measurement

The pH level of water is measured scientifically by, the negative logarithm of hydrogen ions concentration in water and is expressed in moles per liter. The pH in water is largely influence by the carbon dioxide concentration [47]. During the pilot testing, it was found that there have been reported entries in the system dashboard that the acidic level was 6.4 moles per liter, and the highest recorded pH value is 7.7 moles per liter, within the normal acidity limit.

TABLE- II: The pH value (Average) from January 24-30, 2019

Dates	pH Value (Average) moles per liter	
January	***(12:00AM- 11:59AM) PHT***	***(12:00pm- 11:59pm) PHT***
24	7.5	7.3
25	7.1	7.0
26	6.8	6.5
27	6.4	6.8
28	7.0	7.1
29	7.2	7.7
30	7.7	7.7

Ideally, pH value is 7.5 and 8.5, and below or above these values makes the system stressful and no more conducive to fish life [48].The finding of the system on the morning of January 27, 2019 as reflected in Table II has regarded the fishery managers and fishpond owners to conduct remedies, and intervention because the pH level is at 6.4 moles per liter. This indicates that the water and soil are acidic and would affect directly the fish in the pond. A phytoremediation was applied to remove heavy metals present in the fishpond's soil and water through the microbes of the floating and submerged aqua plants.

C. Dissolved Oxygen

The dissolved oxygen (DO) is the extent of gaseous oxygen (O2) that has been dissolved in water [49, 50] and is expressed in milligrams per liter (mg/L). By direct absorption, oxygen passes in the water from the atmosphere/environment or through photosynthesis.

TABLE-III: The Dissolved Oxygen (mg/L) (Average)

Dates	Dissolved Oxygen (mg/L)	
January	(12:00AM- 11:59AM) PHT	(12:00pm- 11:59pm) PHT
24	5.2	5.3
25	5.5	5.4
26	5.7	5.8
27	5.8	5.8
28	5.3	5.4
29	5.5	5.5
30	5.6	5.6

Very high concentration of DO posed a critical effect on the aqua organism and becomes lethal to fish [49]. Table III depicts dissolved oxygen variation; however, its values are within the desirable limits. Dissolved oxygen can be countervailed by pumping into the water to purposely replenish the amount of dissolved oxygen. The desirable DO is 5 and above so that the fishpond is conducive to fish life [49, 50]. In the same case, the aqua plants being used in the phytoremediation can help the system through photosynthesis.

D. Water Level

The system was piloted in a 50m x 40m controlled fishpond in Obando, Bulacan with a depth of 6 feet.

TABLE-IV: The Water Level (Average) from January 24-30, 2019

Dates	AREA 1		AREA 2	
	Water Level (ft)		Water Level (ft)	
January	***(12:00AM- 11:59AM) PHT***	***(12:00pm- 11:59pm) PHT***	***(12:00AM - 11:59AM) PHT***	***(12:00pm - 11:59pm) PHT***
24	5.3	5.3	5.2	5.3
25	5.4	5.4	5.5	5.7
26	5.5	5.3	5.3	5.4
27	5.3	5.6	5.5	5.2
28	5.2	5.7	5.4	5.4
29	5.4	5.2	5.3	5.3
30	5.2	5.4	5.4	5.3

During low tide, the amount of water that can pass through the controlled aqua environment is at 4 feet. The volume of water is maintained so that it could be productive for fish reproduction, breeding, growth and feeding.

In the event that the water level is below 4 feet, the system alerts and notifies the user through the web application dialogue box to conduct remedies such as pumping or irrigating water to the fishpond. Table IV presents the captured data gathered during the 1-week pilot testing.

V. CONCLUSION AND RECOMMENDATION

This study presented the design and development of a precision fishing technology utilized in water quality monitoring with phytoremediation system using a Zigbee-based Wireless Sensor Network (WSN).

The developed system afforded to provide a real-time water quality monitoring using multiple sensors spatially deployed with Wireless Sensor Network using temperature sensor, pH sensor, dissolved oxygen (DO) sensor, and water sensor. P89V51RD2 microcontroller, ZigBee module (XBee module Series upgrade S2 S2C) IEEE 802.15.4 standard, and radio frequency (RF) transceiver were utilized. Each sensor was used for data gathering. Data gathered are converted into an electrical signal and forward to the signal unit and microcontroller. A Zigbee module was used with RF transceiver to connect the nodes, coordinators and routers. Phytoremediation was also used as an alternative solution for soil and water remediation. The researcher recommends improvement in the system such as an embedded design to monitor the amount of heavy metals reduced and removed in the soil and water analyses. Also, a mobile application is recommended for scanning the water colourization and red tide monitoring using image processing. Empirical investigation is also recommended to further enhance and improve the fishing industry, to large-scale system applications. Further studies using recent and advanced remote sensing technologies and IoT-based solutions can be developed to address issues in the primary sector of the economy.

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AUTHORS PROFILE

Dr. Daniel D. Dasig, Jr. holds BSc in Computer Engineering, MSc in Engineering in Computer Engineering, and PhD in Electrical and Computer Engineering degrees. Currently, he is pursuing Doctor in Business Administration degree. He has been a Professorial Lecturer in electrical engineering, environmental engineering, information technology, computer science, and education in the Philippines and abroad. He is an Associate Professor 6 of the Graduate Studies of College of Science and Computer Studies of De La Salle University Dasmarinas since January 2018, and a Professorial Lecturer at the College of Continuing and Advanced Professional Studies of the University of Makati since 2014 where he also served as Research Coordinator in the College of Computer Science. In 2014, he served as Chair of Computer Engineering Department of Jose Rizal University. He also works as part of the Change Management, and software development teams of TELUS- a Canadian telecommunication company since 2011. He is a Lean Six Sigma Certified, ITIL V3 Certified and Certified Project Management Expert.

Dr. Dasig has authored and co-authored textbooks, reference books, and book chapters, and has more than 100 academic and technical papers extending over a wide spectrum of research areas such as in engineering, information technology, education, computer science and social sciences. He is a book Editor of Recent Advances in Big Data and Applications in Education, Springer, Switzerland, and Handbook of IoT and Blockchain: Methods, Solutions, and Recent Advancements, CRC Press- Taylor & Francis Group, USA; and Innovations, Models, and Policies of Green Engineering Technologies for IGI-Global.

He has authored and co-authored book chapters in Springer, and books for higher education and senior high school programs. He has organized and co-organized local and international conferences and was a recipient of Best Paper and Best Paper Presenter awards and fellow. He has an executive roles and active membership to more than 40 professional, research and policy-making organizations such as ICANN-NCSG, Internet Society, ICpEP, and PSITE. He has received numerous global and international awards including the World Class Filipino for Engineering and Information Technology. He is an IEEE member.