Water Quality Monitoring and Control for Aquaculture Based on Wireless Sensor Networks

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Abstract—We have designed and presented a wireless sensor network monitoring and control system for aquaculture. The system can detect and control water quality parameters of temperature, dissolved oxygen content, pH value, and water level in real-time. The sensor nodes collect the water quality parameters and transmit them to the base station host computer through ZigBee wireless communication standard. The host computer is used for data analysis, processing and presentation using LabVIEW software platform. The water quality parameters will be sent to owners through short messages from the base station via the Global System for Mobile (GSM) module for notification. The experimental evaluation of the network performance metrics of quality of communication link, battery performance and data aggregation was presented. The experimental results show that the system has great prospect and can be used to operate in real world environment for optimum control of aquaculture environment.

Index Terms—Water Quality Monitoring; Wireless Sensor Network; Aquaculture; ZigBee; LabVIEW; GSM

I. INTRODUCTION

Aquaculture is increasingly considered as an integral component in the search for global world food security and economic development. The vast majority of aquaculture production takes place in China. The automation of aquaculture systems will allow the industry to improve environmental control, reduce catastrophic losses, reduce production cost, and improve product quality [1]. The most important parameters to be monitored and controlled in an aquaculture system include temperature, dissolved oxygen, pH, ammonia, nitrates, salinity, and alkalinity, since they directly affect animal health, feed utilization, growth rates and carrying capacities [2].

Water temperature affects the feeding pattern and growth of fish. Fish generally experience stress and disease breakout when temperature is chronically near their maximum tolerance or fluctuates suddenly. Warm water holds less dissolved oxygen than cool water. Oxygen consumption is directly linked to size of fish, feeding rate, activity level and pond temperature. The amount of dissolved oxygen in water increases as temperature reduces, and decreases when salinity increases. Low dissolved oxygen concentration is recognized as a major cause of stress, poor appetite, slow growth, disease susceptibility and mortality in aquaculture animals [3]. It is generally accepted that the minimum daily dissolved-oxygen concentration in pond culture systems is of greatest concern. Not only is dissolved oxygen important for fish respiration, it is also important for the survival of phytoplankton, the organism which breaks down toxic ammonia into harmless forms. The acceptable range of pH for fish culture is usually between pH 6.5 to pH 9.0. When water is very alkaline (>pH 9), ammonium in water is converted to toxic ammonia, which can kill fish. On the other hand, acidic water (<pH 5) leaches metals from rocks and sediments. These metals have an adverse effect on the fish’s metabolism rates and ability to take in water through their gills, and can be fatal as well [4]. Since failure of any component can cause catastrophic losses within a short period of time, the system must be reliable and constantly monitored. Thus, precise measurements and controls are necessary for the success of an intensive aquaculture system [5]-[6].

However, there are few applications of systems which could carry out real-time water quality monitoring continuously in China. According to the conventional methods of water quality monitoring, samples of water are taken and transported to a chemical laboratory to analyze the hazardous substances. On the other hand, the maintenance of the measurements and control process is manual influenced by the personal experience [7].

How to realize real-time data collection in a secure, robust, manageable and low-cost manner without long-distance cable connections is still a bottleneck in the development of information monitoring in fish culture. Modern aquaculture environment detection and control technology achieves high-quality, high yield, improves the basic environmental conditions and is one of the key means to promote fish production through the integrated application of bio engineering and computer technology to make the appropriate adjustments, according to the variation of indicators, increase production, and guarantee reliable income [8]-[9]. A properly-controlled system will also be energy efficient since production can be optimized with respect to the various inputs. So a sustainable development of aquaculture environmental factors monitoring and control system for intensive fish farming is inevitable.
Wireless sensor network (WSN) is an important and exciting new technology with great potential for improving current applications in intensive aquaculture [10]. In contrast to wired sensors, the obstacle has been to develop hardware that is capable of transmitting data under difficult circumstances and developing low-cost, long-term energy sources for the sensor nodes. WSN are in intimate connection with the immediate physical environment allowing each sensor to provide detailed information on environment of material that is otherwise difficult to obtain by means of traditional wired instrumentation [11]. In this work, ZigBee wireless communication technology (IEEE 802.15.4) is preferred over other technologies for the development of wireless sensor network due to its low cost and low power consumption property.

This work focuses on the use of multiple sensors to monitor and control the water quality parameters of temperature, dissolved oxygen, pH and water level in aquaculture in real-time. The sensor nodes collect the water quality parameters and transmit them to the base station host computer through ZigBee wireless communication standard. Several measurement and performance analysis to evaluate the reliability, feasibility and effectiveness of the network performance metrics of quality of communication link, battery performance and data aggregation was presented. The system was tested at Tanggu fish farm demonstration base in Tianjin for six months. The key water quality indicators was precisely controlled by relevant actuators, taking timely measures to improve the stability of variety of factors, greatly savings of electrical energy consumption, providing continuous data that can be used to identify trends and improve production and hence increasing income of aquaculture farming.

II. RELATED WORKS

WSN become an important issue in environmental monitoring. The relatively low cost of the devices allow the installation of nodes that can adequately represent the variability present in the environment [11]. WSNs was applied successfully for monitoring of soil water content, temperature and salt in a cabbage farm of Spain semi-arid regions Murcia [12]-[13]. The design of the WSNs included four types sensor networks topology structure nodes deployed in the field. They were soil node, environmental node, water node and gateway node. Furthermore, the software and hardware of each node were given. The management and real time measurement of the whole system were carried by the central processing computer in the farm management office. System testing was carried in two stages, including the laboratory test and the field test. The laboratory test has analyzed mainly the function of the system devices, network performance and energy consumption; measurement range, robustness and reliability of system test were mainly in the field test.

In [14] a ZigBee WSN was developed for monitoring an experimental aquaculture recirculating system. Temperature, dissolved oxygen, water and air pressure as well as electric current sensors were included in the setup. Modules for reading and transmitting sensor values through a ZigBee wireless network were developed and tested. The modules were installed in an aquaculture recirculating system to transmit sensor values to the network coordinator. A monitoring program was created in order to display and store sensor values and to compare them with reference limits. E-mail and an SMS message alert can also be sent to the cellular phone of the system administrator so that immediate action can be taken. A web interface allows internet access to the sensor values.

A WSN based on ZigBee in aquaculture was presented by [15]. The aquaculture monitoring environment has characteristics of multi-measuring points, long measuring time and high complexity measuring conditions. This system achieves the goals of collect, transmit and display multi-parameters such as dissolved oxygen and temperature. In [16] a WSN for continuous monitoring water quality in aquaculture farm was developed. Multi-parameter water quality node, temperature chain node, routing node and an on-site monitoring center were designed and implemented. Multi-parameter water quality node was created for measurement of dissolved oxygen, water level and temperature in sea cucumber ponds. The routing node used to extend the range of continuous monitoring in aquaculture farm. Reference [17] developed a WSN based traceability system for recirculation aquaculture (RATS). The system enables rapid deployment and can acquire water temperature, salinity, dissolved oxygen and pH and achieve real-time data transmission. The RATS was mainly developed using # in Microsoft Visual Studio 2008 integrated with the real-time monitor chart powered by the Matlab M-language dynamic link library. The structure of the WSN to collect and continuously transmit data to the monitoring software was designed by [18]. Then they accomplished the configuration model in the software that enhances the reuse and facility of the monitoring project. Moreover, the monitoring software developed to represent the monitoring hardware and data visualization, and analyze the data with expert knowledge to implement the auto control. The monitoring system has been realization of the digital, intelligent, and effectively ensures the quality of aquaculture water.

Moreover, the use of the ZigBee standard is often seen in agriculture through the use of WSN in order to monitor or control various parameters [19]. Reference [20] conducted a study in real time with the remote measurement of humidity, temperature and brightness of the ambient air. In addition to detect water pollution in irrigation, a ZigBee WSN was installed in agricultural production. In [21] a novel methodology for the monitoring of the agricultural production process based on wireless sensor networks was developed. The authors proposed a methodology consisting of a set of well-defined phases that cover the complete life cycle of WSN applications for agricultural monitoring. An online water monitoring system based on ZigBee and GPRS was developed by [22]. The sensor data were collected and transmitted via ZigBee and GPRS. The data process
procedure was implemented by LabVIEW software. Reference [23] developed a distributed measurement system based on networked smart sensors to monitor aquaculture factors in multi-environment. The system consists of four parts: data collection nodes, routing nodes, on-site monitoring center and remote monitoring center; and can bring-out real-time monitoring water quality parameters and meteorological parameters.

However, the application of their proposed system is still limited by its rather complicated operational requirements and high maintenance cost. Further, none of these studies analyzed battery behavior of sensor nodes in an outdoor environment like our work. Moreover, the systems were not integrated with actuators in nodes for remotely correcting environmental parameters such as dissolved oxygen and water valves. In our work, the graphical user interface (GUI) was designed by LabVIEW software platform so that the users can observe and modify the related values of aquaculture environment. Still, there are many challenges that arise when one wants to get the best performance of the network installed in this wide variety of locations. Problems of control and actuation, information packet loss, battery consumption, as well as aspects related to the real-world environments. Very few results exist to date regarding meeting real-time requirements in WSN. Many other functions must also meet real-time constraints including data fusion and data transmission.

III. SYSTEM DESIGN

The wireless sensors used in this experiment monitor temperature, pH, dissolved oxygen and water level. The sensors measure these parameters at specific time intervals and transmit the data wirelessly to a receiver station. The sampling time interval was set to roughly every 3 minutes in order obtain a long effective transmission communication range and 2.405 GHz was selected as the communication frequency for this application. As shown in Fig. 1, the entire system has a sensor node, communication device and the base station. Accordingly, each sensor node is designed to communicate to the base station via ZigBee communication technology. The base station host computer acts as the central monitoring platform for data analysis, processing and presentation. While the sensor nodes acts as the remote monitoring platform for data acquisition.

A. Sensor Nodes

The sensor nodes consists of data acquisition, data transformation and transmission, and water quality control components. Data acquisition component collects non electricity signals of the most important environmental factors by using various sensors. With the current measurement, pH value is measured by glass electrode method, temperature by thermometer sensing technology and dissolved oxygen sensor by membrane electrode technique. Dissolved oxygen sensors collects fish ponds dissolved oxygen information and converts into electrical signals to provide the necessary condition for subsequent processing circuit. The system uses the dissolved oxygen sensor with a rigid solid structure for automatically compensating sensor membrane permeability due to temperature changes and automatic pressure balance to prevent the diaphragm deformation and to provide material conditions for the accurate collection of information.

The data transformation and transmission is composed of the signal conditioning circuit, data acquisition board, core processing chip and communication module. The low level input signals directly from sensors are converted to serial digital output voltage standard in the range of 0-5V by high performance AD7705 converter chip. This chip uses sigma-delta conversion technique to achieve 16-bit code performance. Also, the device includes self-calibration and system calibration options to eliminate gain and offset errors of the device or system. The signal is then transmitted to the microcontroller (MCU) chip. The sensor nodes uses ATmega16L microcontroller as the core for data acquisition and processing. ATmega16 has an advanced RISC architecture, 113 instructions, 32 general-purpose registers and work at 16 MHz performance up to 16 MIPs, two cycle hardware multipliers, 8-channel 10-bit Analog to Digital Converter (ADC), 32 programmable Input/Output (I/O) ports, 16KB system programmable watchdog timer with independent on chip oscillator, power on reset, programmable power failure detection and on chip calibrated RC oscillator [24]. Then the MCU chip through a comparison with standard parameters issues control signals to drive relays for each actuator motor device. Data and control signals generated are aggregated and transmitted through ZigBee network to the gateway which is connected to the host computer base station. The host computer has priority, records these data for the user to query at any time according to the actual needs and issues commands through a gateway and ZigBee network to control the actuators in case environmental parameters are outside the preset threshold. The data processing microcontroller chip pack the data into the wireless transmission module and enables the gateway to receive the data and transmit them to a host computer for further analysis. The sensor nodes are powered by battery 5V DC. The CC2520 single chip of ZigBee processes the data and then communicates between antenna and gateway wirelessly. CC2520 is the second generation ZigBee/IEEE 802.15.4 RF transceiver in TI Company used for industrial, scientific and medical (ISM), 2.4 GHz band. CC2520 can work at 125 °C which provides the excellent sensitivity, connectivity and can work at low-voltage operation as well. CC2520 supports frame processing, data buffering, burst transmission, data encryption, data authentication, idle channel detection, link quality display and frame timing information thereby reducing the load of main controller.

B. Gateway

The gateway receives command packets, preprocesses and analyzes the data from the sensor nodes and then send to the host computer. The gateway is connected with the base station with serial RS-232 cable. In case the users have not yet received the response data from the
sensor nodes within the time frame set, the sensor nodes will be considered to failure and then text messages will be sent to owners via the base station to notify about maintenance. The monitoring program is installed in the host computer base station that displays results and warns stakeholders through early short message warning. The environmental parameters of the fishpond will be sent to owners through short messages from the host computer via the global system for mobile (GSM) module. In view of the communication requirements between host computer and owners, the use of the GSM network to communicate not only reduces the cost, but also expands the communication range and space. Moreover, the base station sends data on a regular basis to the sensor nodes capture command when the transfer is complete and wait for the sensor node to return the data. If normal environmental parameters from the sensor nodes are received, the base station displays results on the display device. If otherwise the set value text messages are sent to the owners for notification and automatically open the corresponding actuator pump for correcting the respective environmental parameters. With the user-friendly interface, the host computer allows the owners to carry out a number of parameter settings to facilitate monitoring. Also is possible to set a manual command so as to achieve reasonable adjustment and control of systems diversity.

The gateway node comprises of 4 basic modules including communication module, RS-232/USB interface module, MAX-232 and power module. The communication module chosen for this module is the same with that in the sensor node, CC2520. The ZigBee CC2550 uses the serial peripheral interface (SPI) to connect the couple of control lines, and then connect to USB chip through a serial cable. This node receives power from the computer through the SPI bus, which ensures that the node is online all the time. Personal Computer (PC) is used as a processor in place of microcontroller. So in this work, microcontroller is not used at gateway node. However, PC performs the functionality of processor and is used to receive the data from the transmitting node and issue commands to control remote actuator devices.

C. Software Design

The software design of the sensor nodes is mainly carried out using ICCAVR compiler, one of the third-party C compilers recommended by ATMEL Corporation. ICCAVR comply with the ANSI C standard language to develop a suitable tool for the MCU program, easy to use, good technical support and basically has the following characteristics:

ICCAVR is an integrated editor and project manager integrated working environment (IDE).

The status of the system running the host computer is monitored in real time and can analyze, compute, display, print and process data. There are many platforms for development of PC monitoring screen such as KINGVIEW, C, C#, C++, and LabVIEW. In this study, LabVIEW is chosen for software realization. LabVIEW software user interface is as shown in Fig. 2. LabVIEW is a graphical G-language whereas the resulting program is in block diagram form. The production line technology staff can easily learn and use simple procedures which help to maintain, master and apply to practice in a very short period of time. On one hand, the host computer uses LabVIEW software to monitor and process water quality.
Data and on the other, to control actuator devices on remote site. The software can also be set for each of the ponds in order to ensure that the parameters in different species under different weather conditions have a suitable environmental growth [26]-[27].

D. Data Aggregation

Data aggregation, which combines data from multiple sensors, is performed in the firmware of the sensor nodes and monitoring program of the gateway. The network data aggregation can reduce the data packet size, the number of data transmissions and the number of nodes involved in gathering data from a WSN. The most dominating factor for consuming energy of WSNs is communication, i.e., transmitting and receiving messages [28]. Therefore, reducing generation of unnecessary traffics in WSNs enhances their lifetime. In addition, involving as many sensor nodes as possible during data collections by the sink node can utilize maximum resources of every sensor node. Aggregated result of sensor data at the sink node is used for making important decisions. Because WSNs are not always reliable, it cannot be expected that all nodes reply to all request. Therefore, the final aggregated result must be properly derived. For this, the information of the sensor nodes (Node Identifications, IDs) contributing to the final aggregated result must be known by the sink node. And the communication cost of transmitting IDs of all contributed sensor nodes along with the aggregated data must be minimized. Following are some promising reasons for transmitting IDs of sensor nodes along with their sensed data.

To know the exact picture of sensors data by identifying which sensor nodes are sending their data for data aggregation.

Data loss due to collision is inevitable in WSNs. Therefore, IDs of sensor nodes are needed to deal with data loss resiliency and accuracy of the final aggregated result of sensors data at the gateway node.

To know either a sensor node is providing service or not (survivability of a sensor node).

Hence, a gateway node must be aware of node IDs of those sensor nodes which contribute in aggregated value of sensors data in order to derive exact result of the collected data in WSNs. This is possible only when there exists such a scheme which can transmit IDs of all the participating sensor nodes to the sink node. In this work, each sensor node has the capabilities of sensing, aggregating and forwarding data and it can send fixed-length data packets to the gateway node periodically. Finally, the sensor nodes can switch into sleep mode or a low power mode to preserve their energy when they do not need to receive or send data.

We used decentralized fusion architecture whereby data fusion occurs locally at each sensor node on the basis of local observations and the information obtained from sensors. This scheme has the advantage of scalability and tolerant to the addition or loss of sensing nodes or dynamic changes in the network. Due to their energy constraints, sensors need to perform efficient data fusion to extend the lifetime of the network. Lifetime of a sensor network is the number of rounds of data fusion it can perform before the first sensor drains out. This is known as the Maximum Lifetime Data Aggregation (MLDA) problem.

Given: the location & energy of each sensor and the base station (BS). The goal is to find an efficient manner to collect & aggregate reports from the sensors to the BS [29].

\[\text{System model}\]
\[n\text{ sensor nodes (1..n)}\]
Base station (n+1)
Fixed data packet size: k bits
Initial energy of a sensor: \(e_i\)
Receive energy,
\[\text{RX}_i = e_{\text{elec}} \cdot k\]
Transmission energy,
\[\text{TX}_{ij} = e_{\text{elec}} \cdot k + e_{\text{amp}} \cdot d_{ij}^2 \cdot k\]
where \(e_{\text{elec}}\) is the electronic energy and \(e_{\text{amp}}\) is amplifier energy.

**Algorithm**

**Phase One:**
Sensors are grouped into clusters in a node.
Each sensor node consists of a minimum no. of sensors.
The energy of a sensor node is the sum of the energy of all the sensors within it.
Distance between two sensor nodes is the maximum distance between two sensors where, each resides in a different sensor node.

**Apply the MLDA algorithm.**
Software instruction-level parallelism (ILP) is employed to find a near-optimal admissible flow network.

Objective: maximize the lifetime of network (T) under the energy constraints.

Generate schedule(s) from the admissible flow network.

**Phase Two:**
Initialize \{Aggregation Schedule\} = 0.
Life Time, \(T = 0\).
Choose a scheduler from phase 1.
Initialize aggregation tree, A with the BS.
Visit each clusters and add the nodes such that, the residual energy at each edge is maximized.
Add A to the aggregation scheduler.
Increment T by 1.
Repeat steps 3-7 until a node drains out.

**Comments**
Provides a set of data fusion schedules that maximize the lifetime of the network.
Clustering of nodes reduces the time needed to solve the ILP.

![Figure 3. Sensor installation](image)

**Temperature and water level sensors dipped in water**

**Dissolved oxygen sensor dipped in water**

**E. Testing Environment**

The system has been tested in Tanggu district at Tianjin intensive aquaculture base for six months (from
June 4, 2012 to November 25, 2012. The data presented here was taken during the whole testing time. The pond area is 2 acres divided into 4 ponds, pool 3 meters deep. Photos of the project setup and hardware testing for real time data acquisition, analysis and presentation are shown in Fig. 3, Fig. 4, and Fig. 5. Fig. 3 shows dissolved oxygen sensor installation at the Tanggu fish pond. Furthermore, Fig. 4 shows the user interface device for setting user's mobile number and displaying values from sensor nodes and Fig. 5 shows dissolved oxygen aerator pump controlled automatically by the sensor nodes.

The GUI of the monitoring center allows monitoring data obtained from the sensor nodes and observe the behavior of the network in terms of quality of the radio link of each sensor node, data aggregation and battery status. The received signal strength is expressed in dBm. We used two nodes in the test, each being installed in different fish pond.

Considering the project requirements of cost, stability, accuracy, durability and other indicators, this system uses the following sensors:

- Temperature sensor: DS18B20 thermometer, operating voltage range (3-5.5V), temperature range detection of -55~+125°C (-67 to +257°F) and accuracy up to ±0.5 degrees Celsius.

- PH value sensor: PH400/450 series, pH display controller, the pH value measuring range -2.00 to 16.00, pH resolution of 0.01 pH and accuracy is ±0.01pH.

- Dissolved oxygen sensor: D-6800 intelligent dissolved oxygen detector, measuring range: 0-20.00mg/L, automatic range switching and temperature compensation: 0~60°C, resolution: 0.01mg/L, precision: ±0.5%.

- Water level sensor: UXI-LY pressure type level transmitter, range of 1~70m, accuracy: 0.3%FS and temperature range: -10~70°C.

IV. RESULTS AND DISCUSSION

The experimental results of sensor readings, battery performance and communication performance (signal strengths) recorded in every three minutes were monitored during the six months period. Fig. 6 shows monitored data of temperature with fluctuation by more than 5°C during a 24-hour period for the whole experimental duration. Two sets of data sampled automatically from node one and two placed in different fishponds have been compared. The curves correlate well but do not match, due to local biomass conditions in the fish ponds. During daylight hours, energy from the sun warms the water, while heat is lost to the cooler atmosphere at night. Wind and storms affect temperature by breaking up stratification, mixing the water and equally distributing the heat throughout the water column. Fig. 7 shows the monitored data of dissolved oxygen from node one and two respectively. The maximum values of dissolved oxygen recorded was 10.7 Mg/L and 9.93 Mg/L from node one and two respectively. Whereas, the minimum values of dissolved oxygen recorded was 4.50 Mg/L and 4.91 Mg/L from node one and two respectively. It can be noted that dissolved oxygen content did not fall below 4.5 Mg/L set even at night times. This can be explained by the fact that at this level the fishponds were sustained by aerators, thus meeting the objective of preventing fish mortality. These values demonstrate the ability of the controller to maintain the desired set points. Dissolved oxygen normally increases during day light hours when photosynthesis is occurring and decreases at night when respiration continues. Dissolved oxygen curves observed here from node one and two are different due to difference in aquatic animals and availability of phytoplankton in the ponds. It can be seen in Fig. 8 that the pH was relatively stable with standard deviation of ±0.21 and ±0.42 respectively. It can be observed that by being within range, there was no need for controlling the pH, since the values acquired by the software was within the preset range limit. The pH tends to decline in fishponds as bacteria produce acids and carbon dioxide is generated by the fish, algae and phytoplankton. Carbon dioxide reacts with water to form carbonic acid which drives the pH downward. Below a pH of 6.8 the nitrifying bacteria are inhibited and do not remove toxic nitrogen wastes. Optimum pH range in fishponds is maintained through the addition of alkaline buffers. The most commonly used buffers are sodium bicarbonate and calcium carbonate but calcium hydroxide, calcium oxide, and sodium hydroxide have been utilized. These curves change consistently and reasonably. The acquisition data reflects temperature, dissolved oxygen, pH and water level trend appropriately. These figures
Figure 6. The monitored data of temperature collected from 4 June to 25 November, 2012

Figure 7. The monitored data of dissolved oxygen collected from 4 June to November, 2012

Figure 8. The monitored data of pH collected from 4 June to November, 2012

Figure 9. The monitored battery performance data collected from 4 June to November, 2012
show the correctness and feasibility of the fish pond monitoring system. The detailed changes of water level measured by our proposed system are in the same way with satisfactory results.

Sensor nodes were powered with Duracell alkaline battery size Lantern, number MN908, 6V 11.5 Ampere hours. The battery level of all the sensor nodes stayed very stable in the range of 5.05V to 4.39V for the whole experiment duration (Fig. 9). Regression analysis of the battery performance experimental data with a linear fit gave a determination coefficient, $R^2 = 0.9919$, showing that a close relation between the values exists. Part of the power is consumed by the sensors, microcontroller ATmega16L, and the communication module CC2520. The actuators and the gateway are powered by the mains. Since the sensor nodes are operated with batteries, the power supply is very limited and so power saving is therefore of outmost importance in designing, implementing and operating a WSN based monitoring system. In our case, energy consumption is reduced by using low power hardware (sensors, microcontrollers, radio chips) for implementing sensor nodes that consume typically significantly less energy. The hardware and software presented here are designed specifically to address the needs of WSNs namely efficiency power consumption, low cost and scalability that integrates detection, processing and storage. The batteries are unable to supply enough current to power the node once the voltage drops below 2.5V.

The Received Signal Strength Indicator (RSSI) curve for the whole experimental duration is shown in Fig. 10. A low RSSI value represents a bad radio link, a high value a good radio link. The typical receiving sensitivity is -94 dBm. In general the signal strength that reaches the receiver antenna is dependent on the orientation of the antenna and the distance between the transmitter and receiver. This represents an additional source of error which may significantly influence the accuracy of the received signal strength. In order to achieve high signal strength the antennas should be placed in line of sight at distances $\leq 1/r^2$ for avoiding attenuation of antenna signal power in outdoor environment (where $r$ is the distance between transmitter and receiver). However, in real-world environments, this indicator is highly influenced by noises, obstacles, and the type of antenna, which makes it hard to model mathematically. In this case it is important to make a system calibration, where values of RSSI and distances are evaluated ahead of time in a controlled environment.

Similar findings with a remote wireless system for water quality web based monitoring in intensive fish culture were reported by [5, 17]. Rather precise and constant regulation of dissolved oxygen, temperature, water level and pH has been achieved by this system. For example, in six months test of using this system, these environmental parameters were kept at optimal levels where almost all aquatic organisms can survive indefinitely provided other environmental parameters are within allowable limits. Whereas the fish are reasonably comfortable and healthy at 5-6 mg/L dissolved oxygen concentrations, which is in agreement with our findings. Ideally, fish ponds should be at or near oxygen saturation at all times. This system has a structure of receiving and storing water quality information sent from respective sensors in real time and links it with GSM module so that the user can have access to fish pond status at any place in time. Information stored in host computer can be displayed as a graph, with which a user can understand the status of the fish pond in real-time, and user can take corrective action for any possible problems at proper time.

Continuously monitoring real-time environmental parameters and alarms will automatically notify the user of any out of bounds condition that could signal an equipment failure, improper settings, extreme weather conditions etc.

V. Conclusions

This study provides the design of water quality monitoring and control system for aquaculture based on a wireless sensor networks and single chip computer technology as a base in the actual operation. It realizes the monitoring of the water environmental parameters for intensive aquaculture and alarm notification through short message when monitored variables take anomalous values and is suitable for long-term stability under growth conditions thus increasing yield per unit area. The system can monitor the data of temperature, dissolved oxygen, pH, and water level continuously and in real-time. Two nodes have been implemented for six months to evaluate the system feasibility. The sensor data, battery performance and network performance metrics have been analyzed and presented. The pump can be set to auto-start
according to the parameter values and avoid common fisheries problems such as dissolved oxygen depletion due to high water temperature, cloudy weather and pond turn over’s hence avoiding fish kills. The pump working hours will be greatly reduced thus efficient energy consumption and reducing labor cost.

Future works should be enhancing the system remote access to the sensor nodes using internet and data transmission for further analysis. More network performance metrics need to be studied and evaluated to make the system more robust and scalable.

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