Automated Monitoring and Control System for Shrimp Farms Based on Embedded System and Wireless Sensor Network

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***Abstract*—This paper presents a versatile solution in an effort of improving the accuracy in monitoring the environmental conditions and reducing manpower for industrial households shrimp farming. A ZigBee-based wireless sensor network (WSN) was used to monitor the critical environmental conditions and all the control processes are done with the help of a series of low-power embedded MSP430 microcontrollers from Texas Instruments. This system is capable of collecting, analyzing and presenting data on a Graphical User Interface (GUI), programmed with LabVIEW. It also allows the user to get the updated sensor information online based on Google Spreadsheets application, via Internet connectivity, or at any time through the SMS gateway service and sends alert message promptly enabling user interventions when needed. Thereby the system minimizes the effects of environmental fluctuations caused by sudden changes and reduces the expended labor power of farms. Because of that, the proposed system saves the cost of hiring labor as well as the electricity usage. The design promotes a versatile, low-cost, and commercial version which will function best for small to medium sized farming operations as it does not require any refitting or reconstruction of the pond.**

Keywords—Aquaculture, CC2530, MSP430, Wireless Sensor Networks (WSN), ZigBee.

I. INTRODUCTION

In recent years, the development of shrimp farming has been rapidly improving in the Mekong Delta in south-east Vietnam. Successful shrimp farming is reliant on management of the environment as well as good fundamentals such as good seeds and quality food. Currently, famers monitor the environmental conditions in the pond manually and irregularly, mostly according to the farmers' experience which is time-consuming and costly in terms of manpower. The monitoring is usually only done when the farmer has discovered the abnormal condition of the shrimp or when environmental factors change dramatically. When the phenomenon occurs, the procedure to help rebalance the farming environment is usually very complex and expensive. This causes environmental factors to be monitored ineffectively.

Commonly, shrimp farmers use mechanical paddle-wheels that have to be turned on and off manually to slap, beat and churn oxygen into the surface of the water. The system is operated manually based on experience and not based on any actual measurement mechanism. The operation of the device by hand causes huge waste of power. Therefore, the monitoring of the environment on a regular basis and a mechanism for automated control automation is essential.

Currently, a number of shrimp farms closed and automation is being applied in the industry. However, these models require a huge initial investment cost (minimum of three hundred thousand USD to one hectare) and are only suitable for large-scale farming businesses [9]. These models are beyond the investment capacity of shrimp farms of small and medium scale because rehabilitation and reconstruction of the entire pond system is required. Soonhee Han *et al*. has designed and built an environmental monitoring system for aquaculture farms [2], and sends alerts when environmental factors can no longer be guaranteed. However, this system is based on a wired network, so the transmission is not only problematic, but it is also difficult to expand.

By examining the actual needs of enterprises of small and medium sizes, we found that automating some tasks in a scientific way allows us to not only solve the problem of ineffective human resources but also minimize power consumption. At the same time, research also indicates that factors like stratified water temperature, pH, and dissolved oxygen (DO) levels in the water are particularly important. Based on the information gathered, we propose a low-cost system, that is highly interactive and easy-to-use to monitor the possible weak operating environment and some automated workflows. The system provides two important features as follows:

- Continuous monitoring: Our system monitors and records water quality around the clock, based on a Wireless Sensor Network, providing continuous data that can be used to identify trends and improve production. Almost any sensor can be used but currently our system monitors three critical parameters including dissolved oxygen, temperature, and pH. Sensors can measure data at any interval depending on the determinations of the farm operators. Through the use of mathematical algorithms, supported by LabVIEW, operators can store processed data in the units of their choice, simplifying data analysis.
- Automated Control: Aerators, pumps, alarms, or other electrical devices can be controlled based on measured conditions, time schedule, or user requests. For

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example, aerators can be turned on (day or night) when DO measurements reach a preset value. Together with continuous monitoring, automated control keeps the system operating efficiently and evenly.

The remainder of the report presents the following sections. Section II will describe the requirements for system design. Section III introduces the system architecture based on design requirements. The system development will be discussed in detail in section IV. In section V, some initial results obtained will be presented. Section VI concludes and suggests subsequent development of the subject.

II. SYSTEM REQUIREMENTS

For effective management of shrimp ponds, we need early detection of disease problems and the capacity to implement appropriate responses before an outbreak becomes uncontrollable [10]. In most ponds, changes in the health of the shrimp only become apparent over time based on a combination of observations on the condition of shrimp, consumption of food quantity, water quality, etc. More importantly any changes of the environmental factors in the pond will contribute significantly to the overall decline in the total health of the shrimp overall. It is also noted that environmental factors in the ponds are heterogeneous and constantly changing in many ways based on each region, weather, growing conditions, etc. This further complicates shrimp farming. Hence, the importance of monitoring these conditions correctly in terms of continuity using monitoring points of sufficient quantity to arrive at accurate representative monitoring is essential. A wireless sensor network is an advanced solution compared to traditional monitoring. Sensor nodes can be deployed inside the pond which is also an economical savings, and at the same time a way to implement monitoring, control and long-term research.

The proposed monitoring and control system should meet the following requirements:

1) Systematic

- Work to be done at the same place, same time each day or each month.
- Work to be performed and repeated at regular intervals.

2) Responsive

- The information must be available when required.
- Information must be presented in an understandable user friendly way.

3) Interactive

- Allows user response based on the data collected to analyze prospective problems.
- Provides the ability to react promptly to the problems encountered.

4) Predictive

- Data can be used for planning and decision making in the future.

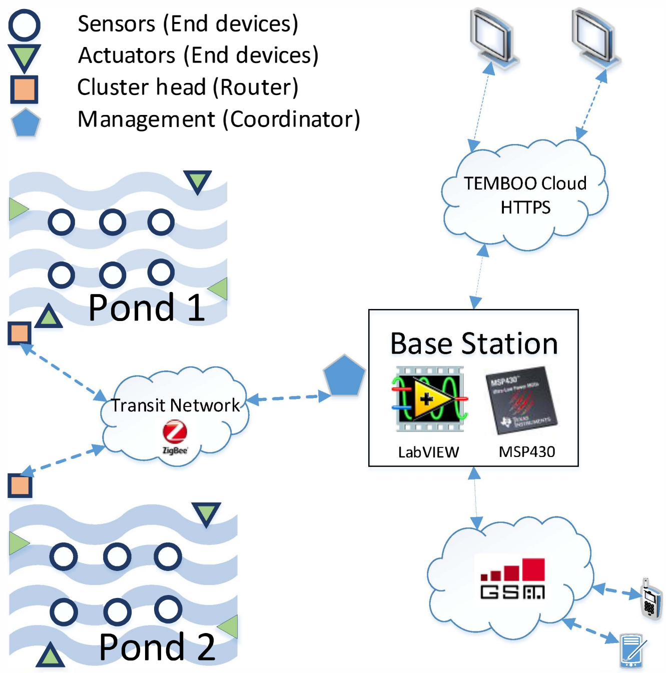

Fig. 1. System architecture of the proposed design.

III. SYSTEM ARCHITECTURE

Figure 1 shows the most important modules that make up our proposed system. To meet the requirements in the previous section, the system will be developed based on the architecture suggested by A. Mainwaring [1] which has been discussed in [4] and [5].

To support the scalability of the system, we used three models of sensor nodes. First, we built a *wireless sensor network* to collect information in each separate pond, the network consists of multiple nodes, and each node will be used to obtain the critical sensor information. Next, the *wireless control network* is used to control the oxygen pumping system at each pond. Then, the sensor nodes as well as control nodes in each pond wirelessly communicate with the master station through a node called the *cluster header*. Finally, a *management station* which is the heart of the proposed system is built and is responsible for many tasks including gathering sensor information, controlling oxygen pumps, etc. All wireless protocols used to communicate between nodes in the sensor network systems are based on the IEEE 802.11.4 standard which was selected for the design because it requires low power consumption.

Principle of Operation:

The data gathered from the sensor nodes is sent to the cluster head, and the cluster head is responsible for data transmission to the base station. The data is then analyzed and presented on a graphical user interface, programmed by LabVIEW. The data is sent to the base station in a time frame consistent with each selected measurement parameter based on material in [10]. This time frame can be appropriately changed according to the analysis on gathered environmental factors.

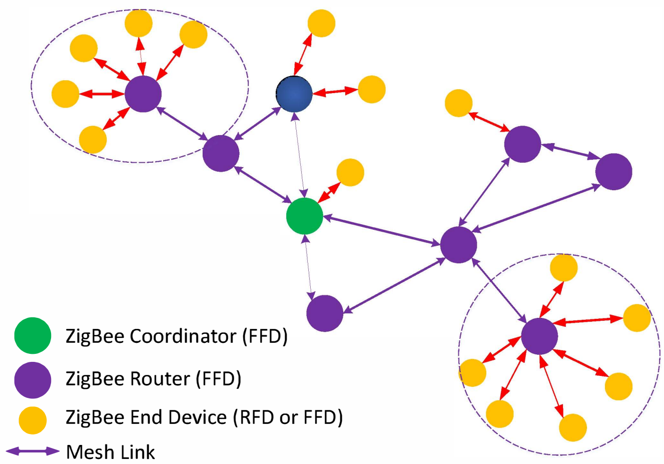

Fig. 2. Mesh topology for the proposed monitoring and control system

The system also provides two options for the purpose of increasing the user's interaction with the system. The first option allows the user to retrieve up-to-date information about the environmental factors in the pond and control equipment easily through the SMS gateway. It provides great utility for the user as they can access the information or receive warnings (when the elements in the pond change and exceed certain level) at any location where GSM services exist.

The other option allows the user to access information about environmental factors in pond via a web-based application called Google Spreadsheets. The application enables the user to observe the data anywhere that they can connect to the Internet.

IV. SYSTEM DEVELOPMENTS

In accordance with the overall system architecture analysis, the implementation of the system consisted of protocol, hardware, and software development.

A. Routing Protocol Design

In order to make in-network communications more efficient, we used the MESH topology with node types defined as follows: (1) end devices (for sensor nodes and control nodes); (2) routers (assigned for the cluster head at each pond); and (3) coordinator (for base station node). Figure 2 shows the structure of the Mesh network deployed in our proposed design.

One of the primary benefits of the MESH architecture is that if an intermediate device fails, or goes offline, or is busy, the information can still be transmitted or received through the alternative path. In the MESH architecture, the in-network nodes are automatically routed to find the most efficient path for transmission in order to avoid packet drops. This is why, MESH architecture is usually referred to as "self-healing" and this is also the reason we chose MESH topology for data transmission in the proposed system.

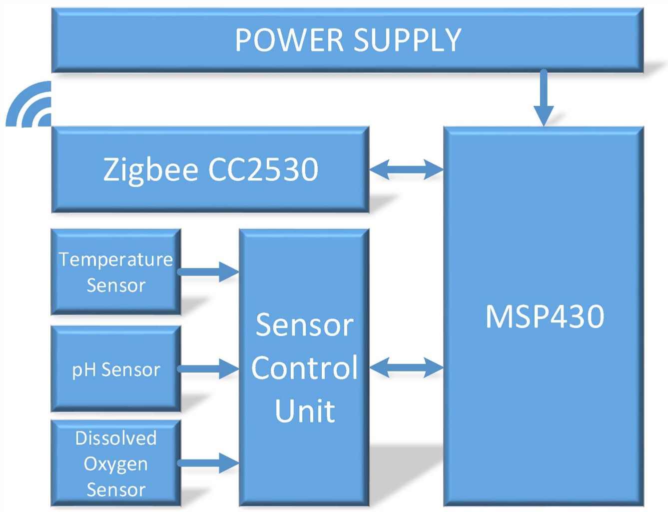

Fig. 3. Sensor end node hardware block diagram

B. Hardware Design

The hardware implemented in this project includes four parts: (1) sensor end node platform; (2) control end node platform; (3) cluster head platform; (4) management node platform.

1) The sensor end node platform

The entire sensor end node platform mainly contains of a microcontroller, a radio chip, and a set of sensors as shown in Figure 3. Each node may have a rechargeable battery with the solar panel as its source supply. This solar panel produces the required voltage and recharges the battery.

Our sensor node platform was developed and implemented with consideration to low-power consumption requirements. Therefore, each node platform consists of a MSP430G2553 microcontroller [12] which is a 16–bit ultra-low power microcontroller, with 16KB of internal flash, 512B RAM, 10-bit ADC, and 1 USART. A CC2530 second generation ZigBee [3] solution, which can be used to develop wireless sensor network (WSN) applications and protocols is used as the transceiver. The MSP430G2553 and CC2530 combination provides a low-power and low-cost solution for our project. In this module, CC2530 and MSP430 communicate with each other via a serial port.

The sensor module is used for data acquisition offering three basic environmental sensing parameters including temperature, pH level, and level of dissolved oxygen.

For temperature measurement, we selected 1-wire digital temperature sensor DS18B20 made by Dallas [6]. DS18B20 measures temperature range from -55 to +125^{o}C and in the range of -10 to +85^{o}C, the accuracy is ±0.5^{o}C. It is able to connect to any GPIO port due to its digital output capabilities.

For pH level measurement, we found that an “Analog pH Meter Kit” [7] can provide us a good solution. This kit consists of a pH sensor circuit board and a pH probe (BNC connector). It provides a full range of pH measurement from 0 to 14pH.

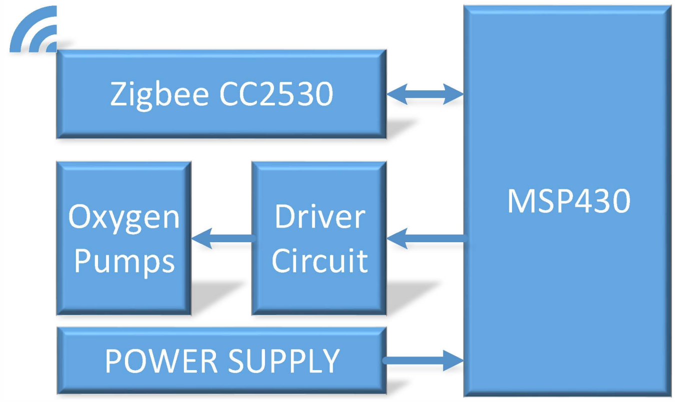

Fig. 4. Control end node hardware block diagram

It works well under a temperature range from 0 to 60°C with a high accuracy of ±0.1pH. Simply connect the PH2.0 interface of the sensor circuit board to any analog input port of MSP430, we can achieve accurate data collection.

For DO measurement, our solution is based on a dissolved oxygen sensor from Atlas Scientific [8]. This sensor device consist of the Atlas Scientific EZO class embedded D.O. circuit and a D.O. probe electrode. Together they offer a very high level of stability and accuracy. This provides a full range D.O. readings from 0.01 to +35.99 mg/L and the accuracy is up to ±0.2. This device supports two data protocols, UART and I2C; therefore, it is compatible with any microcontroller that supports one of these two protocols. It also supports low-power applications thereby reducing the power consumption on this device to only 0.995 mA at 3.3V.

2) The control end node platform

We designed the controller nodes to activate or deactivate the pump oxygen system in accordance with the management system. It can be seen from Figure 4 where the data acquisition module in the sensor node is replaced by a driver module. This driver works according to the control commands from the management module. The commands can be sent timing, or after the data on the levels of dissolved oxygen has been analyzed, or as the user requests.

3) The cluster head platform

Due to the large area of the typical shrimp farm, the end nodes, including sensor nodes and control nodes, of each pond are grouped into a cluster to facilitate the management of the data. The cluster head is built simply by combining MSP430 with a CC2530 ZigBee node configured in Router mode.

4) The management node platform

An intelligent controller is used to manage all the processes that takes place of the farm by its artificial intelligence and sometimes also by getting the control command from the user through a LabVIEW-based graphical user interface, or through a GSM gateway. Many tasks are performed by this management node including collecting sensor data from the end nodes, controlling the pumps, and uploading data to the Internet.

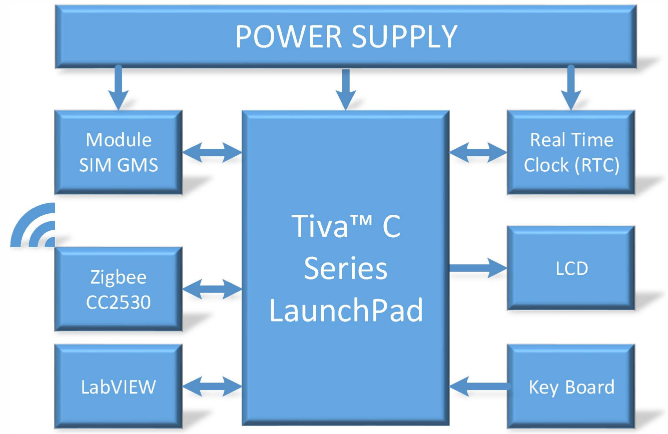

Fig. 5. Management node hardware block diagram

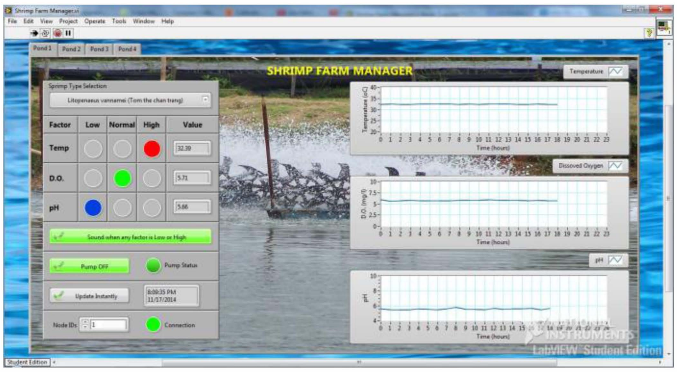

Fig. 6. User interface of the system, in which the user chooses the soil and crop types that cause different values to be given by the automatic irrigation algorithm

The Zigbee module used is the same as what was utilized in the cluster head to provide the Zigbee communication within the constructed wireless sensor networks. It has been configured as a Coordinator with the same PAN ID and the same RF channel as the end nodes.

C. *Software Design*

LabVIEW was used to develop the monitoring software in this study. The gathered sensor data will be displayed in table form and waveform chart at the GUI front panel where the user are able to observe the data for up to 7 prior days. The data received will be compared with the predetermined threshold value to determine that these received values are within or out of safe range; then the system is able to give the appropriate warnings. Warning of any environmental factors will not only be displayed on and at the same time sent to the user's personal mobile phone. The status of the oxygen pumps is also displayed and this can be control manually on the GUI. Figure 6 shows the graphical user interface, programmed with LabVIEW, of the monitoring software development.

SMS Block Design: This block was designed by exploited the advantages of VISA properties in LabVIEW in which the MSP430 and Module SIM 900A communicate with each other via serial port.

D. *Patch Gateways*

Currently we used Tiva C Series TM4C1294 + CC3100 WiFi BoosterPack platform [11] for the hardware utilization. To simplify the project and reduce the time-to-market we decided to program our gateway platform with the power of Temboo [11]; therefore, the gathered sensor information is then easily uploaded to a Google Spreadsheet. Finally, the user is able to read the data from anywhere in the world through a number of web-based interfaces that are supported by Temboo to provide the ubiquitous interfaces to the shrimp farm data.

V. CURRENT RESULTS

A. *Implementation and Experimental Conditions*

In order to test the performance of the monitoring and control system, experiments were carried out at an industrial shrimp farm in Bac Lieu province, which has the second largest area of shrimp ponds in the Mekong Delta region.

In the experiment, a total of 23 nodes were wirelessly networked for monitoring and control on two shrimp farms, of about 4800 square meters each. There were some network limitations involved, but the network can support up to thousands of nodes.

B. *System Performance*

Each sensor end node has been set to receive the in-pond environmental factors (temperature, pH, and dissolved oxygen level) every 2 hours in a normal situation. If any of these observing conditions drops below the predefined threshold, the sensor node will change to a more frequent capture rate of once about every 10 minutes. After the system has been fully operational for 3 months (from July to October, 2014), we found the system can automatically gather environmental factors and provides actuation services promptly. The system also demonstrated the performance of monitoring where the system successfully trigger an automated notification message through SMS gateway when any of these conditions is out of safety range. In addition, the oxygen pump system is also effectively activated or deactivated in accordance with the message from the authorized mobile phone number. However, as this is a work-in-progress project, this testing time is insufficient to confirm the long term reliability of the system.

VI. CONCLUSION AND FUTURE WORKS

This method can be adapted to requests formed in the design process, updating the sensor information and reflecting the real factors of environmental shrimp farming. This system will be labor-saving for the famer and report environmental changes immediately, thereby enabling the farmer to prevent adverse consequences. This is a low cost, ease-to-use and flexible to implement system as it can be integrated into small and medium sized shrimp farms with minimal modifications. Currently this system also provides many options which are user friendly enabling the farmer to manage all the necessary farming factors resulting in increased production.

The system also has high scalability for households or farming businesses on a larger scale. Currently the team continues to test the reliability of the system in real life applications.

Acknowledgment

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References

[1] A. Mainwaring, J. Polastre, R. Szewczyk, and D. Culler, “Wireless Sensor Networks for Habitat Monitoring”, Copyright 2002, Intel Corporation, June 2002.

[2] S. Han, Y. Kang, K. Park and M. Jang. Design of Environment Monitoring System for Aquaculture Farms. Frontiers in the Convergence of Bioscience and Information Technologies (FBIT 2007), pp.889-893, 11-13 Oct. 2007. Jeju City. Korea.

[3] Texas Instruments, “A True System-on-Chip Solution for 2.4-GHz IEEE 802.15.4 and ZigBee Applications,” CC2530 datasheet, Apr. 2009 [Revised Feb. 2011].

[4] G H. Wang, D. Estrin, and L. Girod, “Preprocessing in a Tiered Sensor Network for Habitat Monitoring,” In EURASIP JASP Special Issue on Sensor Networks, 2003.

[5] H. Claussen, “Adapting a Communications Network of Wireless Access Nodes to a Changing Environment,” United States Patent, US 7299069 B2, November 20 2007.

[6] Maxim Integrated, “DS18B20 Programmable Resolution 1-Wire Digital Thermometer”, DS18B20 datasheet, REV: 042208.

[7] DFRobot, “PH meter (SKU: SEN0161),” Aug. 11, 2014. [Online]. Available: http://dfrobot.com/wiki/index.php/PH_meter(SKU:_SEN0161). [Accessed: Nov. 2, 2014].

[8] Atlas Scientific, “EZO™ D.O. Circuit Datasheet”, version 1.1.

[9] My Duyen, “Bac Lieu: Shrimp farming in greenhouses,” Youtube, Jul. 24, 2014 [Video file]. Available: http://www.youtube.com/watch?v=onZt9myfTtA. [Accessed: Jul. 28, 2014].

[10] Chris Robertson, "Australian prawn farming manual: health management for profit," department of primary industries and fisheries, [online document], 2006. Available: Australian Centre for International Agricultural Research, http://aciar.gov.au/publication/cop001 [Accessed: Aug 1, 2014].

[11] Temboo. “Texas Instruments + Temboo: “Program your TI LaunchPad with the power of Temboo,” www.temboo.com. [Online]. Available: https://www.temboo.com/hardware/ti [Accessed: Oct. 05, 2014].

[12] Texas Instruments, “Mixed Signal Microcontroller,” MSP430G2x53 datasheet, Apr. 2011 [Revised May. 2013].