Design and Development of a Sensor Mote for Precision Aquaculture

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Abstract

Precision agriculture has been recently proved that it can effectively improve productivity and quality of farm management by collecting environmental parameters, analyzing and evaluating this data and then making decision on farm management precisely according to the data. Sensor mote plays an important role in precision agriculture since it provides primary inputs (sensor data) to the system.

This paper proposes the design and development of a sensor mote for precision aquaculture applications. The mote consists of two electronic boards: main board and extension board. The main board consists of processing and power units, while the extension board includes both communicating and sensing units. In order to increase the feasibility of connecting to various types of sensor, the mote is designed to provide both 3.3V and 5V with numerous numbers of pins for both analog and digital interfaces. In addition, the mote provides the functionalities of real-time clock (RTC) along with battery monitoring capability, simplifying the implementation of a smart aquaculture management system.

Keywords: precision agriculture, wireless sensor networks, smart farming, wireless sensor node

1. Introduction

Precision agriculture technology has been rapidly deployed and implemented over the years. It has proved that it can effectively improve productivity and quality of farm management by collecting environmental parameters, analyzing and evaluating this data and then making decision on farm management precisely to according to that data. Sensor mote plays an important role in precision agriculture since it provides primary inputs (sensor data) to the system.

In aquaculture industries, precision agriculture technology can greatly improve productivity and reduce management cost. This is because water quality is the most important factor in determining the health of the aqua animal which strongly links to the success of the crop. Although there are many experimental studies and researches on what should be suitable and how to maintain water quality for each individual kind of aqua animal. It is still very difficult, tedious, costly and time-consuming to manage a farm to achieve high yield and efficiency. Due to the fact that only a short period of unsuitable water quality can lethally affect the health of aqua animal, farmers need to have real-time data that can reflect water quality level, in order to help in their farm management decision (e.g., when to start/stop feeding, activating aerator, adjust pH, etc.).

The parameters used in determining water quality in all aquaculture are various but the three key parameters typically used are DO (Dissolved Oxygen), pH and temperature while the suitable level of each parameter depends greatly on the kind of aqua animal [1]. In order to be able to maintain good water quality, farmers need to constantly keep track of all these parameters in real-time and manage the farm so that water quality always stays pleasant for aqua animal. Real-time water quality monitoring done manually is highly infeasible for farmers since it is very costly in terms of man power and time. Furthermore, it is even impossible to perform manually real-time monitoring at night time during which there is high risk in the drop of DO.

With the sensor mote, real-time automatic monitoring of these key parameters can be achieved with ease at low cost and minimum human intervention. With the information gathered from sensor mote in real-time, it is possible for farmers to make decision precisely on how to manage the farm efficiently (e.g., aerator operation, pH and temperature management exactly only when it is needed). There are many sensor motes available in the market. Waspmote [1] is very popular for its compact, modular design and its capability to serve for wide range of applications, including aquaculture. However, it is designed based on proprietary hardware and software platform, making it impossible to interface with third-party sensors. PanStamp AVR [2] is a sensor mote designed to be compact and easy to create applications using its available libraries.

Despite its simplicity, Panstamp does include neither power supply circuitry nor any sensor interfaces, making it difficult to implement an aquaculture application. Wisense [3] is designed to have each subsystem on different board. Each board can be stacked on top of each other to make a sensor mote. Similarly to Panstamp, Wisense requires additional circuitry, in order to make the mote operational.

The work in [4] proposes Mikros platform for smart shrimp hatchery application. The platform is developed based on Tmote Sky with a few adjustments. In this smart shrimp hatchery application, only temperature sensor is used to sense the environment.

This paper proposes the design and development of a sensor mote for precision aquaculture applications. The mote consists of two electronic boards: main board and extension board. The main board consists of processing and power units, while the extension board includes communicating and sensing units. In order to increase the feasibility of connecting to various type of sensors, it is designed to provide both 3.3V and 5V with numerous numbers of pins for both analog and digital interfaces. In addition, the mote provides the functionalities of real-time clock (RTC) along with battery monitoring capability, simplifying the implementation of a smart aquaculture management system.

The rest of the paper is organized as follows. Section 2 describes the design and development of the sensor mote for aquaculture management systems. Section 3 then explains the deployment of the sensor mote along with the results discussions. We finally conclude our work in Section 4.

2. Sensor Mote Design

2.1 Main board

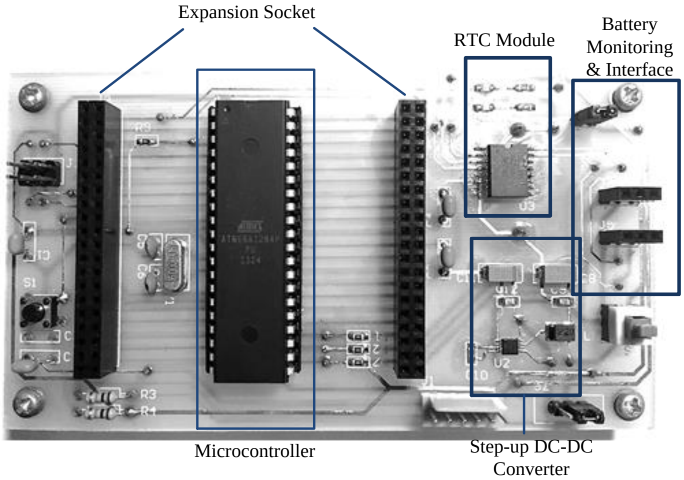


Fig. 1. The proposed main board of the mote for aquaculture applications.

In this work, we adopt the mote architecture proposed in [5-6] which divides mote functionalities and circuitry into 4 units (e.g., processing, communicating, sensing and powering units). The main CPU for the processing unit used in the mote is DIP-40 ATmega1284p, an 8-bit microcontroller with 16 MHz, 128 KB flash memory, 16 KB RAM, 4KB EEPROM. This microcontroller can work with a wide range of voltage (1.9-5.5 V) and it supports sleep mode which can help to lower the mote's power consumption significantly when implemented. There are the total of 32 pins for digital interface, 2 pins for serial interface, SPI, I^2C, and can support devices (e.g., such as sensors) in both 3.3 V and 5 V.

The DS3232 is used for RTC (real-time clock) module due to its high accuracy and low-power consumption. Also, DS3232 can easily be scheduled for the mote to go into a sleep or a wake up mode. To ensure that the mote's time always stays accurate even during which the mote is out of power or in a sleeping mode, there is a backup battery on the back of the main board devoted solely for RTC module. Furthermore, the mote is designed to be used with 1-cell battery of 3.7-4.5 V. In order to support external interfaces that possibly require higher voltage, MAX1674 is used for our step-up DC-DC converter to covert the voltage from 3.7 to 5 V with the maximum current of 1 A. In this design, we have also integrated the battery monitoring module MAX1043 on the main board. This provides the information of current available power of the battery which can be used in determining both the data sensing and sleep and wake intervals.

2.2 Extension Board

The extension board is used for mounting/connecting sensing, communicating and other external devices. It can easily be attached/deattached on top of the main board. Fig. 2 shows the detail of the extension board. This includes various types of interfaces (e.g., digital, analog, control, power and others). The following are the devices attached to the extension board for aquaculture applications. Three types of sensors (pH, DO and temperature) are connected on the extension board to monitor main indicators of water quality in aquaculture. Fig. 3 shows the digital pH sensor with pH circuit version 4.0 from AtlasScienctific that is used for this work. This sensor can measure pH between 0.01 – 14.00 with the resolution of 0.01. DO is the most sensitive parameter among the 3 to be monitored in aquaculture. This is because only a short duration of DO depletion at the lethal level can lead to the death of aquatic animal [1]. Here we use digital DO sensor, shown in Fig. 4, from AtlasScientific.

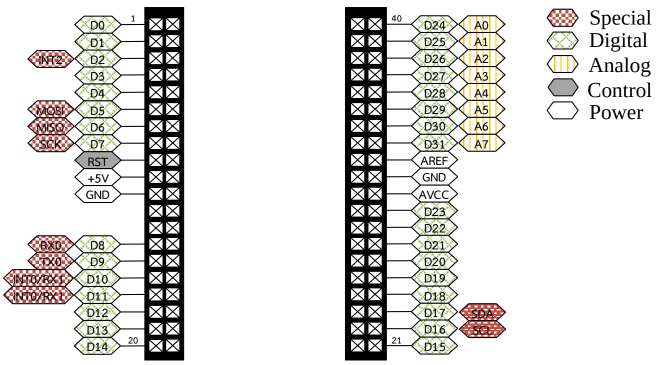


Fig. 2. The design of an extension board of the mote.

Fig. 3. pH sensor circuit version 4.0 with probe, from AtlasScientific.

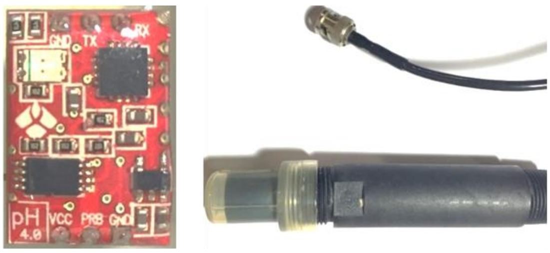


Fig. 4 DO sensor circuit version 6.0 with probe from AtlasScientific.

Fig. 5. DS18B20 Temperature sensor from Dallas Semiconductor.

The measurement of the DO is in mg/L with the resolution of 0.001. To measure water temperature in the pond, we use digital temperature sensor DS18B20 from Dallas Semiconductor, as shown in Fig.5. It can sense temperature in the range of 55 – 125 °C with the resolution of 0.001.

For communication between sensor mote and the server, we use Xbee Pro Zigbee S2 from Digi which utilizes both Zigbee and IEEE 802.15.4 protocols.

3. Deployment Setup and Results

Fig. 6 shows the experiment setup at the shrimp farm in Ratchaburi province, Thailand. Specifically, three sensor motes are deployed at the edge of clay three shrimp ponds. Each pond has approximately the same size of of 2 Rais (~ 0.8 Acres). DO, pH and temperature sensors are placed approximately 15 cm. above the pond bed. The pond and water depths are 2 m and 1.5 m, respectively. Typically, each shrimp cultivation crop lasts approximately 90 days. We start deploying the motes and collecting data mid August 2017, when cultivation is about 15 days old. We leave the motes to collect data for 30 days. The mote communicates with the server, where all sensor data are collected, via Zigbee protocol. After retrieving the data, the server notifies the farm manager's mobile devices, via the Internet, if there is any parameter that needs attention.

In order for the system to initiate notification sending process, the threshold must be set, for each of the parameters monitored. The thresholds for each parameter are set according to the farm manager preference. In this experiment, the thresholds are set as follows: DO must stays above 3 mg/L, temperature and pH must stay between 25 – 33 °C and 7-7.8, respectively. Notification will be sent promptly if either one of the parameters exceeds the threshold.

Although we collect the data for 30 days, due to the space limit, we only show certain set of result here. Fig. 7 shows the results collected within 72 hours when cultivation is 30 days old. As can be seen, during the 72 hour period, DO shows the repetitive pattern during the 24 hours in that high DO can be expected during the day while low DO can be experienced during the night time. Despite the drop of DO during the night, DO is shown to be always well above the threshold.

Typically, pH value in the pond is lowest in early morning and gets to its highest in the afternoon. Collected data shown in Fig. 7(b) confirms the claim and indicates that pH of the water needs attention from farm manager constantly throughout this 72 hours. Temperature data shown in Fig. 7(c) exhibits the same pattern on each day such that water temperature is at its lowest (28 ℃) in early morning and then get increased to its maximum of 32 ℃ in the afternoon. During the 72 hour period, water temperature stays suitable for shrimp cultivation.

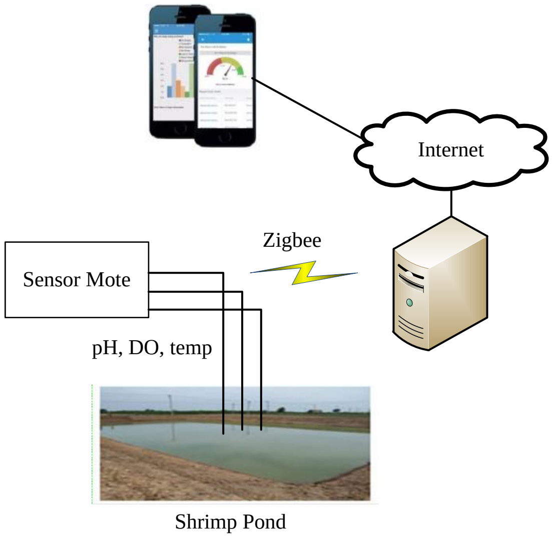
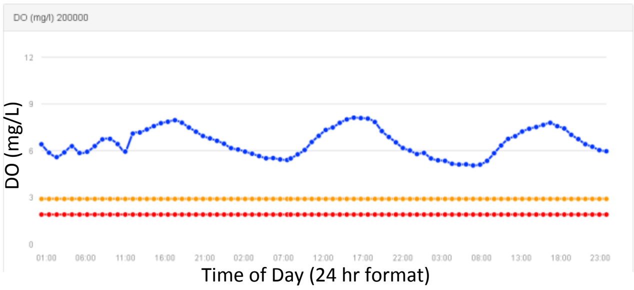
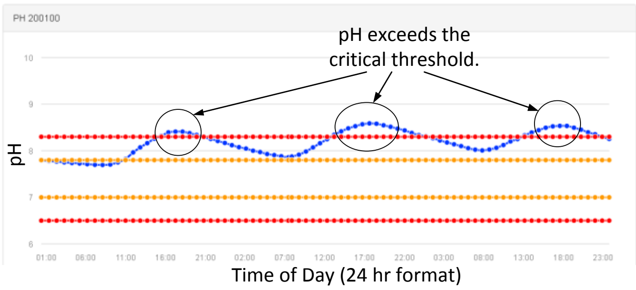


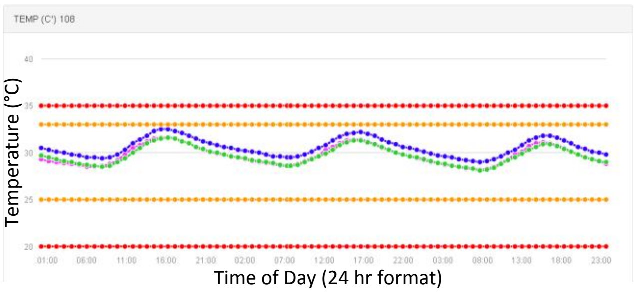
Fig. 6. Experiment setup at shrimp farm in Ratchaburi province, Thailand.



(a) pH



(b) DO



(c) Temperature

Fig. 7. Sensor data obtained from sensor mote during 72 hour collection period.

4. Conclusion

This paper proposes the design and development of a sensor mote for precision aquaculture applications. The mote consists of two electronic boards: main board and extension board. The main board consists of processing and power units, while the extension board consists of communicating and sensing units. In order to increase the feasibility of connecting to various type of sensors, it is designed to provide both 3.3V and 5V with numerous number of pins for both analog and digital interfaces. In addition, the mote provides the functionalities of real-time clock (RTC) along with battery monitoring capability, simplifying the implementation of a smart aquaculture management system.

In order to verify the stability and robustness of the mote, the proposed motes have been deployed and tested in a shrimp farm in Ratchaburi province, Thailand for pH, DO and temperature data collection, for the duration of 30 days. The results show that the motes can work continuously (except for the time at which sensors and battery are under periodically maintenance for 10 minutes every 2 weeks) through the period. Interestingly, data collected from the motes reveals very useful information to the farm manager on when precisely to turn on/off aerators, add water or other substances into the pond in order to treat water to have the suitable environment for shrimp cultivation. Without this information, aerators are regularly turned on between 8 pm- 6am everyday which leads to unproductive use of electrical power.

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