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Application note

Design and deployment of wireless sensor networks for aquaculture monitoring and control based on virtual instruments

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ABSTRACT

Aquaculture is moving toward an intensive controlled environment production with a significant increase in production, but at a cost of increased risk of catastrophic loss due to equipment or management failures. In addition, managers of intensive production facilities need accurate, real-time information on system status and performance in order to maximize their potential. This work has developed and deployed low cost short-range modules of wireless sensor network based on ZigBee standard and virtual instruments technology in order to monitor and control an aquaculture system in real time. The system consists of smart sensor nodes, coordinator/gateway node and personal computer (PC). The smart sensor nodes monitor environmental parameters such as dissolved oxygen, water temperature, pH and water level using relevant sensors, transmit this information to the coordinator/gateway node through ZigBee network and receive control signals for actuator control. The coordinator/gateway node receives data acquired and sends command to PC in order to achieve human–computer visualization interface. The graphical user interface (GUI) was designed by LabWindows/CVI software platform so that users can observe, investigate and analyze the related scientific and accuracy of parameters in aquaculture environment. We have implemented our method for two sensor network nodes deployed in fish ponds and monitored the results for six months indicating that the power management and networking solutions adopted to work in practice, lead to maximize monitoring, control as well as the recording of the aquaculture system. It effectively reduces the probability of high risk of fish mortality through enabling constant monitoring of the critical parameters in the aquaculture environment. This situation in effect increases economic benefit for aquaculture, consumer confidence and safety while reducing labor cost and energy consumption.

1. Introduction

Globally, aquaculture is the fastest growing food sector and its economic importance is increasing concomitantly (FAO, 2009). Intensive aquaculture is seen as a solution to high demands for fish and sea food amidst declining sea and ocean stocks. Unlike crops and animal farming on land, fish is highly susceptible to pollutants in water as they ingest water during the respiratory process. Unfortunately, aquaculture production is vulnerable to adverse effects of environmental conditions. For example disease outbreaks in recent years have affected farmed Atlantic salmon in Chile, Oysters in Europe, and marine shrimp farming in several countries in Asia, South America and Africa, resulting in partial or sometimes total loss of production. In 2010, aquaculture in China suffered production losses of 1.7 million tones caused by natural disasters, diseases and pollution (FAO, 2012).

The monitoring of environmental parameters in shrimp aquaculture allows the control and good management of water quality in shrimp ponds, avoiding the occurrence of unfavorable conditions that can be harmful for organisms (Ferreira et al., 2011). In addition, some species are observed to be highly sensitive to low dissolved oxygen in water, temperature, salinity and pH level of the water. Thus the deployment of sensors is not only important to monitor water quality but also to provide early warning for contaminants in water as well (Harun et al., 2012).

However, one of the pertinent yet persistent issues faced by aquaculture farmers is how to efficiently monitor the water quality of their fish ponds. Computer-based controls provide the capability to monitor and adjust many operations independently and simultaneously. Effective application of a controller is critical especially in the design of automated controlled environmental monitoring system. The advances in sensor technologies, mobile computing, and wireless communications now allow water quality scientists to acquire, process and transmit an array of data while still in the field, or remotely from off-side laboratories. Real-time remote monitoring technologies offer several advantages over historical

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monitoring techniques by streamlining the data collection process, potentially minimizing human errors and time delays, reducing overall cost of data collection, and significantly increasing the quantity and quality of data on temporal and spatial scales (Glasgow et al., 2004).

Modern water quality analysis requires a constant monitoring of the different water quality parameters in the major catchments. This creates a new paradigm in water quality sensing as the information is to be collected and eventually transferred wirelessly over a certain period of time. Therefore, accurate measurement of such water quality parameters as pH, dissolved oxygen, water temperature, water level, among others, is required at different depths on the high spatial resolution. Measuring instruments should be part of the wireless distributed sensor networks, miniature, and cheap sensors that would likely be the most preferable option (Zhuiykov, 2010).

The principal constraint in pond production is availability of dissolved oxygen. Dissolved oxygen is considered to be the most critical quality parameter, since shrimps in the low dissolved oxygen concentrations are more susceptible to diseases. Dissolved oxygen is needed in a number of ways; it is needed for fish respiration, waste decomposition and algal respiration (Bosma and Verdegem, 2011). It is of great importance to all aquatic organisms and it is considered to be an important factor which reflects physical and biological processes taking place in the water body. Moreover, it is of importance to the production and support of life as it is also necessary for the decomposition of organic matter (Tamot et al., 2008). The minimum levels of dissolved oxygen recommended by authors oscillate between 4 and 5 ppm. It is recommended that dissolved oxygen level should be kept above 2 ppm. Mineralization of organic matter and nitrification require oxygen and reaction rates require maintenance of oxygen concentration above a critical threshold (typically >2–3 mg l^{-1}). The threshold minimum oxygen concentration that is required for nitrification is similar to the minimum required for god fish growth (John, 2006).

Temperature is also a key variable to determining tropical shrimp growth and immune response. In high values of temperature, the demand of dissolved oxygen increases. Changes in temperature rates can stress shrimp and consequently high mortality rates can be present in the population. Temperature controls solubility of gases, chemical reactions and toxicity of ammonia. The demand of dissolved oxygen increases when the temperature is high.

High salinity concentrations reduce dissolved oxygen in water ponds. Extremely low or high pH stresses shrimp, causes soft shell and poor survival (Chien, 1992). Water bodies with 6.5 to 9 pH concentrations are appropriate for aquaculture production. Reproduction decreases out of this range. Acid death appears with values below than 4.0 and an alkaline death in values above 11 (Carbajal et al., 2011).

In recent years, recognition of these problems has raised concerns by regulatory agencies which are tasked with evaluating water resources in attempts to ensure that environmental levels of physical variables are maintained within established compliance conditions. This has resulted into more recent monitoring programs being initiated toward including continuous data collection by on-site water monitoring instruments. These programs have the advantage that, constant monitoring can be carried out rapidly to detect changes and trends in critical parameters. Continuous in environmental parameters monitoring provides important early warning information to decision-makers as they can respond timely and appropriately to the situation (Glasgow et al., 2004).

Wireless sensor network (WSN) monitoring schemes have the advantage of easy installation, convenient maintenance and cost effective. Moreover they are update, flexible as to information and inspection as compared to traditional wire monitoring system. WSN devices are now widely used for real-time environmental monitoring as well as in agriculture, on ground that, they allow conditions to be monitored continuously and on a remote basis. They have proven to be powerful tools for monitoring short-term variations in these parameters particularly in enclosed fish and shrimp ponds, automated measuring systems of water properties, such as dissolved oxygen, temperature, pH, and wind velocity (Yoshikawa et al., 2007).

Among network standards, ZigBee specializes in low-cost, low power and short range communications based on IEEE 802.15.4 standards for the physical (PHY) and medium access control (MAC) layers. In addition, the ZigBee standards add application support and network layers, together with security and power management routines. ZigBee technology can further provide a low cost and easy deployment monitoring technology to be used in high fish density aquaculture. Moreover, the wireless nature of the ZigBee network makes it simple to change sensor positions depending on the monitoring requirements and adjustments as biomass of the system increases with fish growth. Of equal importance is that, the network transmission speed and response time is fast enough for application since notification of abnormal events to the authorized personnel is done in few seconds after failure event. This work has developed and deployed low cost modules of wireless sensor network based on ZigBee standard in order to monitor and control an aquaculture system.

The main contributions of this work can be summarized as follows:

(1) An architecture that meets the strict efficiency and flexibility requirements of the wireless sensor networks.
(2) An implementation of the architecture using current microcontroller and low power radio technology.
(3) System software that compliments the hardware capabilities and provide support for sensor network and actuator applications.
(4) Water quality monitoring and control system. Real-time water quality measurement adds another dimension to the issue of power consumption of the WSN system since one has to take into account the contribution of energy consumed by the water quality sensors in the overall energy consumption of the water monitoring system. We propose an energy consumption minimization strategy where a wake-up mechanism triggers sleeping/wake-up modes is used to minimize energy consumption.
(5) An experimental verification of our monitoring system. We have implemented our method for two sensor network nodes deployed in fish ponds and present the results of our experiments for six months.

The rest of the paper is organized as follows. In Section 2, we present the motivation behind our work and some necessary related works. In Section 3, we present the system description of the hardware design and sensors selection. In Section 4, we present the system software development. In Section 5, we present results and discussion. We conclude this paper in Section 6 and provide future insights to our research.

2. Motivation and related works

In recent years, considerable amount of work has been done regarding WSN related issues yet interactions with the outside world are still not yet fully explored. Till now they have not yet become widespread and used in the various applications in which they can provide tremendous benefits. In addition, there are still only a limited number of commercial WSN-based solutions available in the market. This is not surprising given the challenges related to their design and performance, power consumption constraints of