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Developing WSN-based traceability system for recirculation aquaculture

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ABSTRACT

Aquaculture has moved from conventional open systems to high density and highly productive land-based recirculation systems. Consumers have increased consumption of fish and fish products due to recognition of their nutritional value along with social progress and the improvement of living standards. A traceability system is considered as an effective tool to guarantee safety in fish products and improve the supply chain transparency. This paper developed a Wireless Sensor Network (WSN) based Traceability System for Recirculation Aquaculture (RATS). System tests shows that the WSN-based traceability system has comparable data accuracy and advantage of easy installment and configuration.
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1. Introduction

With continuous growth of the world's population, the problems of land shortages and insufficient food supplies become increasingly serious. Therefore, aquaculture is becoming an important component in agricultural production. According to the FAO report (2003), aquaculture is likely to be the greatest source of increased fish production, and its share in total food fish supply by 2030 is estimated almost equal to the food fish supply from capture fisheries [1]. During the past years of improving the aquaculture output, which is based on year-round growth at optimum rates with greatly reduced land and water requirements, coupled with a high degree of environmental control, the aquaculture trend has emerged from conventional open systems to high density and highly productive land-based recirculation systems. This trend is manifested at experimental and pilot scale and in a growing number of commercial cases [2–4]. China has been the biggest country in aquaculture in terms of the quantity of total output of aquatic products for 16 years.

From a consumer's perspective, fish is an important part of a healthy diet. It is an excellent source of quality proteins, essential fatty acids (omega-3) and many other nutrients important for optimal health and prevention of diseases [5]. Consumers around the world increased consumption of fish and fish products in recent years due to recognition of their nutritional value. Fish consumption in China also increased significantly in recent years due to an increased national GDP and substantial increase in citizens' disposable income. The average consumption of fish and related products will be 12 kg at the end of 2010 according to estimates by the Chinese Ministry of Agriculture [6,7].

Recirculation systems are mechanically sophisticated and biologically complex. Component failures, poor water quality, stress, diseases, and off-flavor are common problems in poorly managed recirculation systems. Those problems often cause product quality and safety problems. Some software systems are developed to support their management. It is reported

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that in the United States, Germany, Norway, Japan, Sweden and many other countries, water disinfection, purification, oxygen, and temperature can be controlled automatically [8–12]. As far as water quality monitoring is concerned, Germany, France, Denmark, Norway, Japan, the United States and other countries have established a comprehensive water quality monitoring system for aquaculture water temperature, pH, dissolved oxygen and other important water quality parameters, so that complete automation of water quality monitoring can be achieved [13–16]. Most of China's recirculation aquaculture enterprises have important water quality monitor systems. For example, Lu et al. [17] developed an on-line water quality monitor system based on MCS-51, which realized the on-line monitoring of water quality. Qin and Zhao [18] established a C/S structured network aquaculture monitor system based on TCP/IP. Cui et al. [19] designed a remote data acquisition system for recirculation aquaculture based on GPRS, which enabled usage of mobile situations.

Traceability has been defined in ISO8042 as the ability to trace the history, application or location of an entity by means of recorded identification. As the traceability system is an effective method to measure food quality and safety, the EU, the United States and Australia and other developed countries have introduced laws and regulations to enforce traceability systems in food-supply chains. However, the integration of the latest recirculating aquaculture software with traceability system to enhance aquatic quality monitoring has not been explored.

Moreover, in the recirculation aquaculture environment, the use of fixed sensors with wired networks to achieve water quality monitoring system has obvious deficiencies. First, in order to achieve optimum growth environment of the aquaculture objects, the inside of the workshops are hot and humid. Warm vapor of sea water affects the use of hardware devices and shortens their life. This increases the instability and risks of application of cabling systems. Second, because of the parallel connection of ponds of one water circulating and purifying equipment, data sampled in one pond can represent the condition of a group. Every time a pond is randomly sampled for data collection, a set of fixed sensors and network infrastructure would be wasted.

Wireless sensor network is a cross-multidisciplinary, integrated, cutting-edge area of research that combines sensor technology, embedded computing, networking and wireless communication technology and distributed processing. It can sense and collect information of monitoring objects in environments and sends information to the end-user via wireless and multi-hop networks. Wireless transmission has many advantages over transmission with wire such as low-cost, mobility, fast deployment and special occasion usage [20,21]. WSN has been adopted and applied in agricultural [22–26], environmental monitoring [27,28], remote control [29], industrial [30] and many other important areas.

Based on the above discussion, this research adopts WSN as the fundamental network infrastructure and develops a traceability system for recirculation aquaculture with integrated decision support function (RATS). The system enables rapid deployment and can acquire water temperature, salinity, dissolved oxygen and pH and achieve real-time data transmission.

A brief introduction of the system is presented in this section. In the following sections the system analysis is covered, the system design and implementations are demonstrated. The system evaluation and experimental results are presented later. This is followed by the conclusion, remarks from this research as well as future work.

2. System analysis

2.1. The survey design and analysis

Multiple methods were adopted for the users' requirements of RATS including: document collection, observation and interviews.

The documents about aquaculture water quality standards, Hazard Analysis Critical Control Point (HACCP) project in aquaculture process, and water quality logs in workshops were collected to determine the key parameters in system development.

The observations were taken 3 times a day at the chosen workshop, i.e. in the morning, afternoon and evening and continued for 3 days in order to fully observe the culture routine management, including the time and frequency of feeding, water temperature, pH, salinity and dissolved oxygen record.

Interviews were conducted to explore the system requirements which consisted of two parts: one part is the functional requirement; while the other is requirement for the module functions. A list was formulated with managers and workers in Tianjin city with the support from Tianjin Agricultural University (TAU). People on the list described their work flows, whether they knew traceability system and what they wanted in a traceability system. In particular, they were asked about their most concerned water quality indicators and the weight for each. The interviews with the managers and workers were spread out over several days. In total 6 managers and 30 workers were invited to participate in the survey. The initial requirement structure was formulated based on the interviews.

2.2. Users' need for the system

The fundamental features, key modules and functions of the RATS were extracted from the questionnaires and interviews, as listed in Tables 1 and 2.

Table 1
The scientific prototype of the system.

A recirculation aquaculture traceability system based on wireless sensor networks should:
• Be an integrated platform of hardware automatically monitoring and transmitting information with the software automatically processing the information via the embedded models and knowledge. • Realize reliable water quality indicator collection and transmission. • Real-time upload and store records for delivery of feed and medicine. • Achieve aquaculture operation process traceability and enable to find the smallest faults subset and define responsibilities in case a products' quality and safety event occurs. • Allow consumers to query information with the graphical user interface (GUI). • Improve decision support in an aquaculture enterprise.

Table 2
Requirements for modules and their functions of the system.

Module	Function
Data sampling and transmission	Collect and transmit water quality indicators based on WSN.
Water quality monitor	Real-time water quality monitor based on the former functional module.
Aquaculture information recording	Upload and record daily aquaculture information including feeding, pond transform and medicine usage based on wireless communication.
Warning and troubleshooting	Give early warning signals when the indicator has a trend of exceeding the threshold, find the smallest faults subset and define responsibilities when a products' quality and safety event occurs.
Statistics and decision support	Generate reports and charts for management reference in decision-making.
Web service	Provide consumers with information on the aquatic products on the Web.

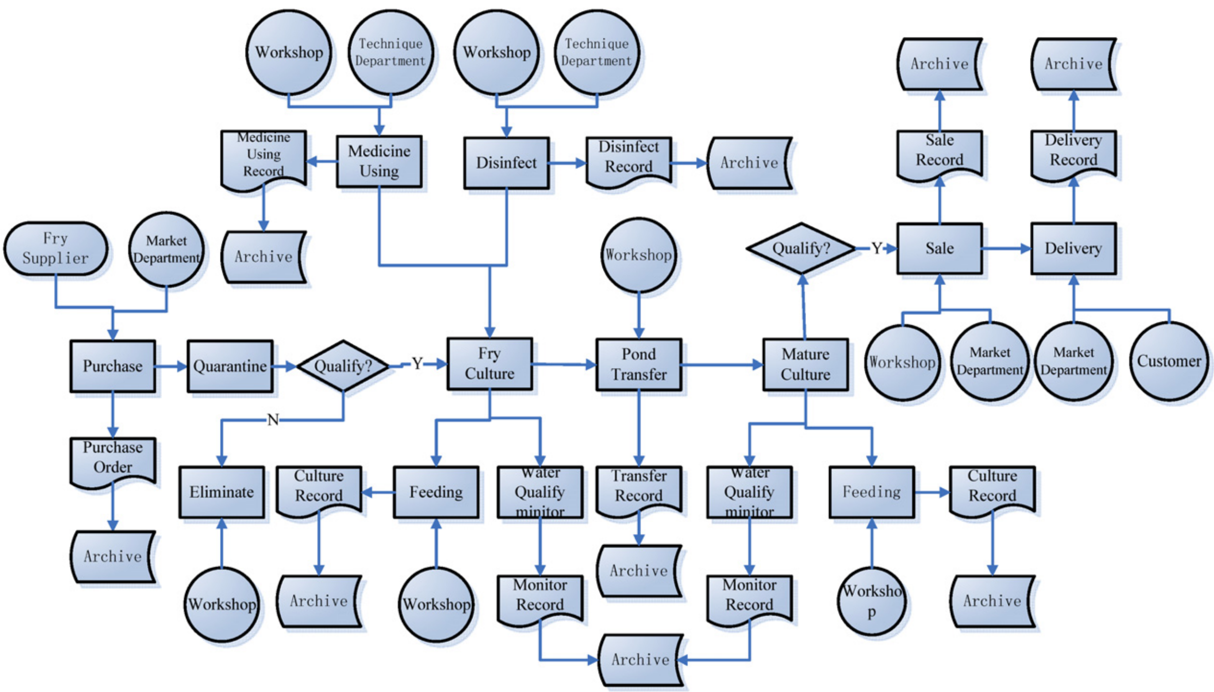


Fig. 1. The recirculation aquaculture business flow.

2.3. Recirculation aquaculture business flow analyse

The recirculation aquaculture business flow below is based on interviews and observations (in Fig. 1):

The aquaculture process mainly consists of five activities: procurement and quarantine, feeding, pond transfer, water quality monitoring, and medicine usage.

Business node 1: The market department and suppliers quarantine the fry together, only qualified fry are purchased.

Business node 2: Feeding activities need to record the type of feed (batch number), weight, feeding time, workers, etc. It is the operation to ensure the aquatic products' normal growth.

Business node 3: Water quality monitor indicators include the detection of water temperature, gravity, dissolved oxygen, pH, nitro–nitrogen content and amino nitrogen content. Water quality should be consistent with NY5052-2001 standard.

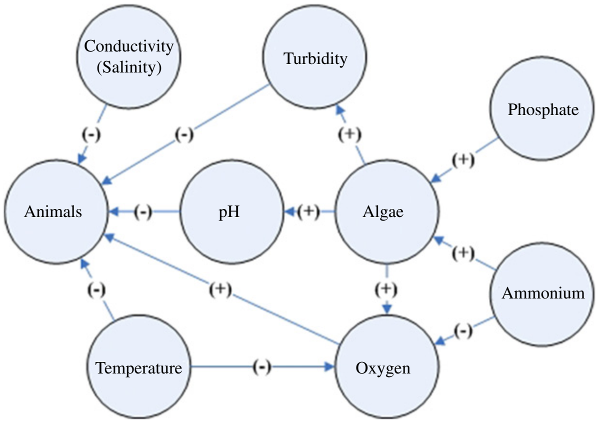


Fig. 2. The relationship between water quality indicators and aquatics.

Business node 4: Pond transfer is a specialized step in recirculation aquaculture. Records of source pond, target pond, fish quantity, operation time, operator and the reasons are needed. Pond transfer information is an important part in the traceability system.

Business node 5: Medicine usage and disinfection are low frequency activities in recirculation aquaculture. Medicine categories should be consistent with the NY5071-2002 standard. Records of medicine categories (batch number), usage, dosage, application location, time and operator are needed. Medicine is forbidden when fish will be at the mature culture stage. Withdrawal period is to ensure that the products are consistent with NY5070 standards in order to avoid medicine deposition in the human body.

2.4. Water quality monitor indicators identification

Water quality is considered to be one of the most important monitoring and control objects in the safety monitoring subsystem in an aquaculture environment. The parameters should be sampled and sent in real-time to the host computer in order to control the water circulating and purifying equipment and update the database in the traceability system.

Fig. 2 illustrates the relationship between water quality indicators and aquatics quality according to Shi [31]. The plus sign indicates the element at the starting point of the arrow has a positive effect on the element at the end of the arrow, while the minus sign indicates a negative effect. It shows that dissolved oxygen, temperature, pH, salinity, phosphate and ammonia have a significant impact on the aquatics. Real-time water quality monitor systems should give priority to these indicators. Taking into account the wireless sensors' ability and user's requirements, the temperature, pH, dissolved oxygen and conductivity (salinity) are selected as the basic monitoring indicators.

3. System design and implementation

3.1. System computing structure design

Similar to most wireless sensor information systems, the RATS adopts a three-layer architecture.

-*The Remote Layer* includes sensor nodes specially designed for application and wireless handsets.

In the wireless sensor network based RATS, the remote nodes float in the ponds and sample the water temperature, salinity, dissolved oxygen and pH value. The data are treated as a Zigbee payload and encapsulated in packets. The packets are transmitted in the form of multi-hop via a self-organized and self-configured Zigbee network to the wireless sensor network gateway. The gateway serves as a converter and a pipe. It collects the data in the packets from the nodes and sends them to a database server via WLAN.

Besides sensor nodes, wireless handsets with an RFID (Radio Frequency Identification) module and RFID tags are introduced into the system. There are four types of RFID tags: (1) operator ID tags that are tied to the operators' wrist, (2) pond ID tags that are attached to the pond wall, (3) and (4) are feed/drug-info card that save the feed/drug's batch number. In order to record and upload the information on feed and drug use in real-time, operators should scan their ID tag, pond ID tag and feed/drug-info card and then put the feed or drug into the pond. Once the previous operation completed, the operators input the feed/drug consumption and press the 'Confirm' button. A record containing the operator ID, pond ID and feed/drug information will be sent by handset to a wireless AP that is linked to the server layer.

-*The Server Layer* is the pipeline that connects the users and remote nodes. This layer provides an integrated and reliable data access services. Server layer provides different business functions according to the realizations of the client layer (C/S or B/S).

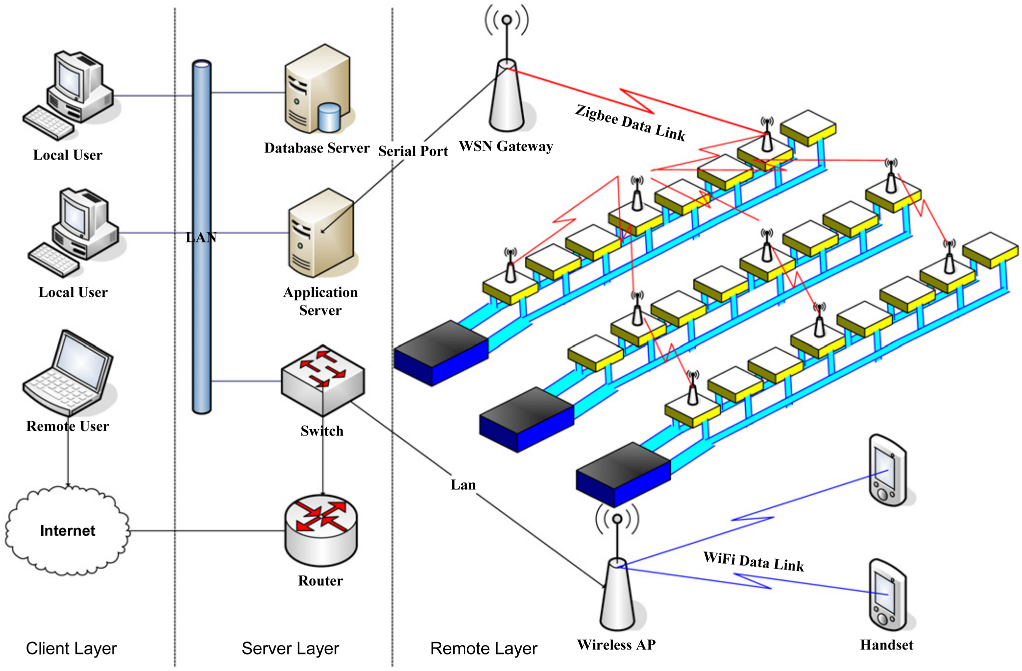


Fig. 3. The RATS system architecture.

Table 3
Comparison of Zigbee, Bluetooth and WiFi.

	Zigbee	Bluetooth	WiFi
Frequency	2.4 G	2.4 G	2.4 G
Range	30 m–1.6 km	30–300 ft	100–150 ft
Data rate	250 kbps	1 Mbps	11–54 Mbps
Power consumption	Low	Medium	High
Cost	Low	Low	High
Modulation/protocol	DSSS, CSMA/CA	FHSS	DSSS/CCK, OFDM

In RATS the server layer consists of a database server and an application server. A PostgreSQL service is running on the database server. It communicates with the gateway in the remote layer using WLAN. All data uploaded from the gateway and wireless AP is first classified and then stored in different tables in the database for different usage. The application server reads the data in the database server and uses them as the input of business logic in the traceability system and the feedback of the automatic control system. These data are processed by the business logic model and sent to the traceability system end-user from both the local area network and the Internet.

-*The Client Layer* mainly provides the user visualization environment and a GUI to end-users to easily manage and use data. The client layer of this system combines C/S and B/S architecture.

C/S model is responsible to connect the hardware with software and provide services to the users inside the enterprise. Users from the enterprise may be concerned about the water quality details in every group, including the past, current and the tendency of the information. So a system with data display and decision support is needed. Scatter and line charts are necessary to local users. The B/S model is designed to provide traceability service to aquatic consumers. Users from the Internet visit the traceability system web site to ensure that the aquatics they bought are reliable, so an active webpage with information summary is enough. All the data that supports the end-users are from the nodes. The only service difference between local and remote users are the data process and display methods.

Fig. 3 shows the 3 layer computing architecture in the recirculation aquaculture traceability system.

3.2. Communication protocol selection for wireless network

There are three most common wireless transmission protocols and standards, i.e. WiFi, Bluetooth and Zigbee. Table 3 expresses the advantages and limitations of each standard.

-*Wireless Sensor Node*: Zigbee is considered as the most suitable for wireless sensor networks because of its low power consumption and simple networking configuration [32]. Zigbee, established by the Zigbee Alliance for Wireless Personal Area Network (WPAN), adds network, security and application software to the IEEE 802.15.4 standard. Zigbee operates on

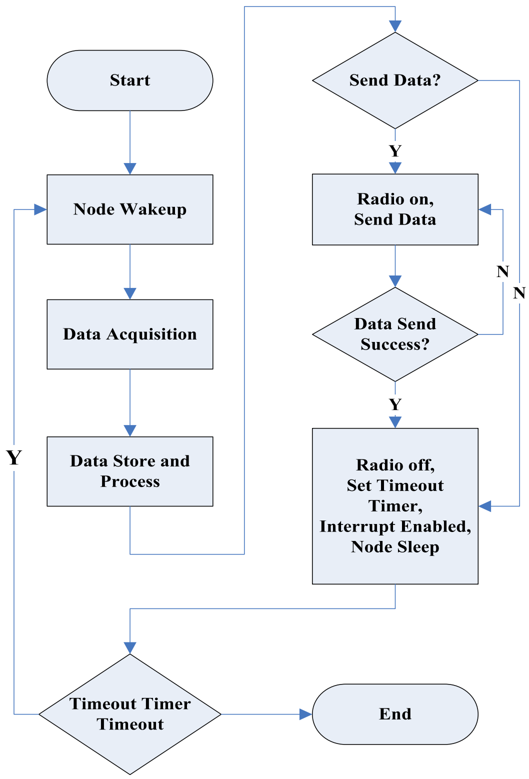


Fig. 4. Statement transfer sequence of a node.

the Industrial, Scientific and Medical (ISM) band. For example, in the 2.4 GHz band there are 16 Zigbee channels, with a 5 MHz bandwidth for each channel. The low cost and low power consumption property makes it suitable for applications in industrial control, embedded sensing, medical data collection, smoke and intruder warning, building automation and home automation.

-*Wireless Handset*: The official name of WiFi (Wireless Fidelity) is "IEEE 802.11b". As with Bluetooth, WiFi also belongs in the office and home use short-range wireless technology. Its maximum transmission rate is 54 Mbps and it can adjust the transmission rate according to signal strength. Because of its low cost, portability and high speed characteristics, WiFi has been introduced into handset short-range wireless communication applications for many years and considered mature and reliable [33].

3.3. Construction of the WSN node

Bare WSN nodes have the capacity of routing, transferring and receiving data packets. In order to sample the water temperature, salinity, dissolved oxygen and pH values, 4 sensors for each parameter are installed on one node. A data acquisition board is fixed to collect signals sent by the sensors and send them to the node. The MDA300 data acquisition board is designed as a general measurement platform for the XM2110 (IRIS) node. Its primary applications are precision agriculture and irrigation control. The XM2110 (IRIS) node can cooperate with the MDA300 by the serial port UART on both printed circuit boards (PCBs).

Additionally, an analog signal transmission circuit is in need to convert the 4–20 mA current signal output by sensors into MDA300 analog channels' 0–2.5 V voltage signal input. Every sensor is in contact with a transmission circuit which consists of an isolation transmitter and a resistor. The isolation transmitter is used to convert current signals into voltage signals. The resistor is used to limit the maximum output voltage.

The illumination of the recirculation aquaculture work shop is always weak. Sometimes in order to achieve the most suitable environment for fish, the workshop may be completely in darkness for several days. This situation makes the use of solar cells in the node not feasible, so a battery is in needed and the node power consumption is considered.

The node sleeps most of the time in order to save power. It activates when data acquisition happens. Acquired data is stored and packed and sent to its parent node. Once the data has been sent, the radio is turned off, an interrupt is enabled and a timeout timer is reset. The above process forms a complete cycle.

The flowchart of the statement transfer sequence of a node is given in Fig. 4.

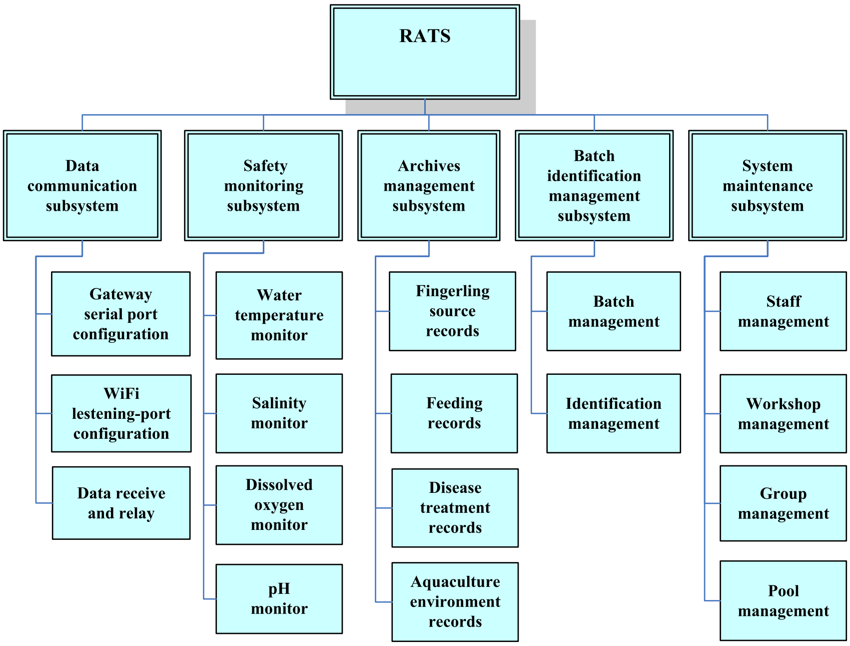


Fig. 5. Function modules.

3.4. Software systems structure

The software system for a local end-user is known as RATS. Based on the work flow analysis and the HACCP of recirculation aquaculture, the RATS' functional modules were given to encompass the aquatic products' life-cycle. The RATS consists of five subsystems (Fig. 5):

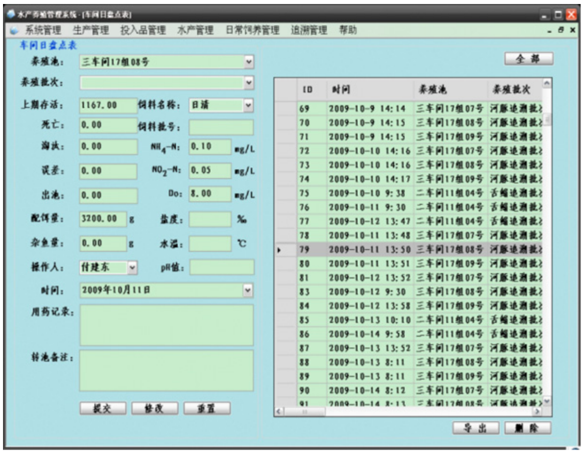
- The data communication subsystem is responsible for ensuring the correct configuration on the ports and to relay received data to the database. It enables users to set gateway serial port configurations and handset WiFi communication listening ports.
- The safety monitoring subsystem is responsible for aquaculture environment monitoring. It includes four modules: a water temperature monitor, salinity monitor, dissolved oxygen monitor and pH monitor.
- The archives management subsystem is responsible for maintaining the historical data in aquaculture. The data includes fingerling source records, feeding records, disease treatment records and aquaculture environment records.
- The batch identification management subsystem is responsible for the batch management in breeding and the bar codes retrospective in sales. It includes two modules: batch management and identification management.
- The system maintenance subsystem is responsible for the maintenance of basic aquaculture environment information such as the stuff, workshops, groups and ponds.

The RATS maintains a database for the data acquired by the wireless sensor nodes and handsets; it also provides a facility to add/edit the fundamental data in daily production. The system provides options for searching records, viewing the water quality records according to key words and plotting graphs for each parameter. It also provides an automatic management for feed and medicines.

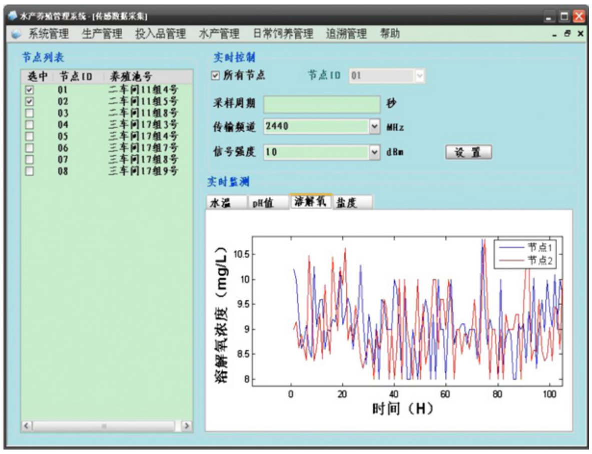
The application has an access control mechanism which makes it more secure. For example, each staff in the enterprise has an RFID tag for identification; only by reading a tag with access privileges via a card reader can the system logon interface be passed.

3.5. Software systems development

-*Wireless sensor node development*: The software on the wireless nodes was programmed using the nesC language and executes on the tinyOS platform. The MDA300 data acquisition module and multi-hop data communication module in Crossbow's demo case were re-used to 'wire' the node program. The digital–analog convert and the linear regression module were integrated into the node program to reduce the energy consumption on wireless communication. Water quality monitoring data were transmitted from nodes to the gateway and uploaded to the server by the FTDI-2232D USB virtual serial port. The COMx at the server-side is responsible for monitoring and capturing all the data uploaded from the gateway. Data were stored in a PostgreSQL database and distributed by socket port 18 000 for more LAN use.



(a) The interface of the prototype system for traceability information input.



(b) The module for data acquisition monitoring and control via wireless sensor node.

Fig. 6. RATS software design for enterprise management.

-*The system development and demonstration*: The RATS was mainly developed using C# in Microsoft Visual Studio 2008 integrated with the real-time monitor chart powered by the Matlab M-language dynamic link library.

Fig. 6(a) is the interface of the prototype system for the traceability information input. The interface is responsible for collecting the relevant traceability information, which cannot achieve automatic acquisition by wireless sensor node or handset. It also provides a manner of editing historical data. The screen layout consists of main menus, a data edit zone on the left and a data grid zone on the right. Users can click the relevant menu to fulfill the expectant function. The data edit zone on the left shows the current access interface of the subsystem. The data grid zone on the right shows all historical data from the database in the current function. Once users select a data row in the grid, data in each cell will be displayed in a text box in the left editable zone. Then the user can edit them.

Fig. 6(b) shows the module for data acquisition monitoring and control via wireless sensor node. All active node IDs and their location are listed in the list view in the left window. If the check box in front of a node is checked, the real-time monitoring data from this node will display at the format of line chart of monitoring on the right tab control, which includes four tabs, i.e. water temperature, pH, dissolved oxygen and conductivity (salinity). The user can configure the nodes' sample frequency, signal channel and strength via the GUI of the real-time control zone on the top-right.

Fig. 7 shows the terminal interface for consumers to query the traceability information.

Consumers can select two kinds of input methods to input the traceability code as Fig. 7(a) shows: bar code scan and keyboard input. If the method of bar code scan is selected, the scanner affiliated with the terminal is active to read a matrix bar code. The alternative method is that the user can input the traceability code by a virtual keyboard. After the traceability code is input and the 'Query' button clicked, a new window (Fig. 7(b)) will pop up and display the traceability information of the aquatic products. Different from previous traceability systems, a virtual tag will appear in the top of the window. It gives the basic information about both the aquatic animal and the aquaculture enterprise. Traceability labels attached on packages should be exactly the same with the virtual one. The extended information is listed in the window below for aquatic products: information of breeding time, pond, feed, medicines and water quality. After inquiry, a user can click the 'Back' button and exit the system.

4. System test and evaluation

4.1. Recirculation aquaculture environment selected

With the support of the project partner: TAU, the aquaculture factory located in Binhai District, Tianjin is selected for the system testing and evaluation, the factory has three main floor workshops. Two of them are fully-closed recirculation aquaculture setups. Workshop 1 was selected as the test base. The whole workshop is divided into fourteen groups. Each group has eight ponds and a set of water circulating and purifying equipment. Water is circulating in a closed loop of eight ponds driving by circulation equipment. Fig. 8 shows the workshop environment.

4.2. System test scenario and results

The sensors' output is an analog signal in the form of a voltage while the four parameters are measured in different physical quantities. It is important to note the relationship between those measures.

(a) The query interface for consumers.

(b) The result interface after the query.

Fig. 7. Interfaces of RATS for consumers.

Fig. 8. The workshop environment.

Table 4
Statistical analysis of the calibration and prediction samples sets, i.e., the data ranges, means and standard deviation (S.D.)

Characteristic	Item	Calibration	Validation
Water temperature (°C)	No.	147	49
	Range	26.4–28.1	26.4–28.1
	Mean	27.2326	27.2346
	S.D.	0.5488	0.5577

Take water temperature for example, the experiment to find the relationship between voltage and Celsius was implemented as follows.

A node with a water temperature sensor and a thermocouple digital thermometer are put into the same pond at a water temperature of 28 °C at the same time. Record the voltage of the sensor and the temperature value on the thermometer once a minute. The experiment lasted for 200 min and a total 196 groups of valid data were obtained. All data were then divided into four groups. Three-quarters were used for the calibration regression model while others for validation. A linear regression method was used to describe the relationship between voltage and Celsius. Table 4 illustrates the summary statistics for all samples selected in each data set. Indicators to evaluate the quality of the regression model are correlation of calibration (R_C) and validation (R_V), standard error of calibration (*SEC*) and error of prediction (*SEP*).

The regression result shows that the accuracy of the data from the sensors are satisfactory, with the $SEC = 0.546$ and $SEP = 0.557$. A significant linear correlation are found from the regression, with the $R_C = 0.989$ and $R_V = 0.997$.

A ladder-like layout of the data points show that the resolution of the thermometer used in the experiment is lower than that of sensors. This increases the mean square error of the regression results. At the same time, water temperature changes in a short range, which to some extent, reduces the reliability of regression. However, by considering the low *SEC*, *SEP* and high R_C and R_V, it is feasible to build the data collection and monitor function for the traceability system using wireless sensor technology.

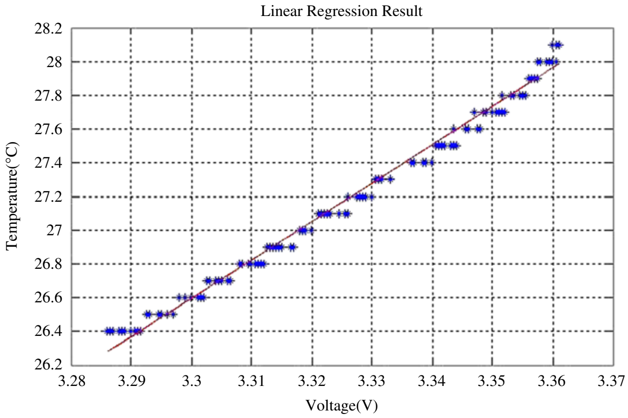


Fig. 9. Linear regression result for water temperature.

Table 5
Effectiveness analysis before and after RATS' deployment.

Index number	Index content	Before deployment	After deployment
1	Management precision	Day/week	Minute/second
2	Data acquisition	Incomplete artificial collection	Automatic accurate mass capture
3	Traceability	Fuzzy	Precise positioning
4	Exception management	Artificial judgment with delay	Automatic real-time warning
5	Quality analysis	Empirically with delay	Accurate, real-time
6	Development and deployment efficiency	None	Code reusable, place to use
7	Maintainability	None	Modularity, replaceable code and nodes
8	User-friendliness	None	Well-designed interface, easy to use
9	Information security	Paper archives, easily damaged or lost	Database backup and recovery
10	Information sharing	Producer only	Producer and consumers

Fig. 9 gives the linear regression result for voltage and Celsius.

4.3. System evaluation

System evaluation measures the current performance and provides the basis for future improvement of the system. The system evaluation on RATS was implemented after it ran normally for 8 months (from October 2009 to May 2010) in order to estimate the technological capacity, performance and system utilization.

Three people from the China Agricultural University (CAU), four from TAU and three from the enterprise were invited to participate in a committee to form an evaluation framework for the traceability system based on the views of system building and maintenance, user experience and external influences. They also reviewed and suggested changes to the software. System improvement suggestions included: (1) traceability information security on Web, (2) accuracy of medication records in the database, (3) fine-tuning the system menu and interface design. Effectiveness analysis before and after RATS' deployment are shown below in Table 5.

5. Discussions and conclusions

This paper reports a WSN based traceability system for aquaculture. The system is developed on the basis of successful experience of wireless sensor networks and traceability systems for food. The WSN technology enables a real-time and mobility data acquisition without network infrastructure. The data accuracy from sensors is satisfactory and even higher than that of conventional means.

Compared with the traditional system, the WSN-based RATS integrated WSN with traceability system can automate many tasks including water quality monitoring and daily business flow. It realizes a cross-communication information flow between the manager, the worker and the consumer.

The system test and experiment evaluation proved itself an effective aquatic quality management tool that leads to maximize monitoring and recording of the aquaculture work flow. It effectively reduces the probability of the high risk of aquatic diseases during the culture process through enabling constant monitoring the critical parameters in the culture environment.

As a result, a traceability system of aquaculture does not only increase economic benefits for the aquaculture enterprise but also improve consumer confidence in aquatic quality and safety. The integrated system can not only collect the water parameters for aquaculture traceability system in the culture process objectively and scientifically, it also provides theoretical support for establishing data integration network and general framework solution of data collection for recirculation aquaculture via wireless sensor networks.

This work can be extended for future work in many directions. For example, as remote wireless sensor networks through the integration with GSM networks, automatic control of important issues for recirculation aquaculture through integration with water treatment equipments.

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References

[1] FAO, Report of the expert consultation on international fish trade, 2003.
[2] Michael P. Masser, J. Rakocy, T.M. Losordo, Recirculation aquaculture tank production systems management of recirculation systems, SRAC Publication 452 (1999) 1–12.
[3] www.usf.uni-osnabrueck.de/projects/AquacultureUzbekistan/pdf/RAS.pdf.
[4] Wang Nengyi, New technologies for recirculating aquaculture, Fisheries Modernization 33 (1) (2006) 9–16.
[5] Birgisdottir, M. Kiely, J.A. Martinez, et al., Validity of a food frequency questionnaire to assess intake of seafood in adults in three European countries, Food Control 19 (2008) 648–653.
[6] Feng Wang, Jian Zhang, Weisong Mu, Zetian Fu, Xiaoshuan Zhang, Consumers' perception toward quality and safety of fishery products, Beijing, China, Food Control 20 (2009) 918–922.
[7] Xi Ren, Xiaoshuan Zhang, Weisong Mu, Zetian Fu, Design and implementation of tilapia breeding quality safety traceability system based on web, Computer Engineering and Design 30 (16) (2009) 3883–3886.
[8] Gang Qin, Clark C.K. Liu, N. Harold Richman, James E.T. Moncur, Aquaculture wastewater treatment and reuse by wind-driven reverse osmosis membrane technology: a pilot study on Coconut Island, Hawaii, Aquacultural Engineering 32 (2005) 365–378.
[9] Milko A. Jorquera, Gustavo Valencia, Mitsuru Eguchi, Masahiko Katayose, Carlos Riquelme, Disinfection of seawater for hatchery aquaculture systems using electrolytic water treatment, Aquaculture 207 (2002) 213–224.
[10] Torsten E.I. Wik, Björn T. Lindén, Per I. Wramner, Integrated dynamic aquaculture and wastewater treatment modelling for recirculating aquaculture systems, Aquaculture 287 (2009) 361–370.
[11] C. Schuster, H. Stelz, Reduction in the make-up water in semi-closed recirculating aquaculture systems, Aquacultural Engineering 17 (1998) 167–174.
[12] Simon J. Cripps, Asbjørn Bergheim, Solids management and removal for intensive land-based aquaculture production systems, Aquacultural Engineering 22 (2000) 33–56.
[13] Xichang Wang, Observations on the fishery of Norway, Journal of Shanghai Fisheries University 5 (1996) 217–220.
[14] Howard B. Glasgow, JoAnn M. Burkholder, Robert E. Reed, Alan J. Lewitus, Joseph E. Kleinman, Real-time remote monitoring of water quality: a review of current applications, and advancements in sensor, telemetry, and computing technologies, Journal of Experimental Marine Biology and Ecology 300 (2004) 409–448.
[15] J. Tschmelak, et al., Automated Water Analyser Computer Supported System (AWACSS) part I: project objectives, basic technology, immunoassay development, software design and networking, Biosensors and Bioelectronics 20 (2005) 1499–1508.
[16] Zizhong Qi, Xiao-Hua Zhang, Nico Boon, Peter Bossier, Probiotics in aquaculture of China—current state, problems and prospect, Aquaculture 290 (2009) 15–21.
[17] Wenhua Lu, Xinming Fan, Xu Jing, An on-line detection and measurement system of water quality, Journal of Yancheng Institute of Technology (Natural Science) 15 (2002) 50–52. 61.
[18] Yun Qin, De-an Zhao, Application of winsock on the data monitor and control of aquaculture, Journal of Agricultural Mechanization Research 9 (2006) 171–173.
[19] Yu-ling Cui, Jianmin Ban, Weizhong Lu, Research of distributed water-quality monitoring system based on network, Microcomputer Information 22 (1) (2006) 167–169. 252.
[20] Ning Wang, Naiqian Zhang, Maohua Wang, Wireless sensors in agriculture and food industry—recent development and future perspective, Computers and Electronics in Agriculture 50 (2006) 1–14.
[21] Li Cui, Hailing Ju, Yong Miao, Tianpu Li, Wei Liu, Ze Zhao, Overview of wireless sensor networks, Journal of Computer Research and Development 42 (1) (2005) 163–174.
[22] Raul Morais, Miguel Fernandes, Samuel G. Matos, Carlos Serodio, P.J.S.G. Ferreira, M.J.C.S. Reis, A Zigbee multi-powered wireless acquisition device for remote sensing applications in precision viticulture, Computers and Electronics in Agriculture 62 (2008) 94–106.
[23] G. Vellidis, M. Tucker, C. Perry, C. Kvien, C. Bednarz, A real-time wireless smart sensor array for scheduling irrigation, Computers and Electronics in Agriculture 61 (2008) 44–50.
[24] E.S. Nadimi, H.T. Søgaard, Observer Kalman filter identification and multiple-model adaptive estimation technique for classifying animal behavior using wireless sensor networks, Computers and Electronics in Agriculture 68 (2009) 9–17.
[25] F.J. Pierce, T.V. Elliott, Regional and on-farm wireless sensor networks for agricultural systems in Eastern Washington, Computers and Electronics in Agriculture 61 (2008) 32–43.
[26] Mohammad Abdel Kareem Jaradat, Moh'd A. Al-Nimr, Moh'd Noor Alhamad, Smoke modified environment for crop frost protection: a fuzzy logic approach, Computers and Electronics in Agriculture 64 (2008) 104–110.
[27] A. Cerpa, J. Elson, M. Hamilton, J. Zhao, Habitat monitoring: application driver for wireless communications technology, ACM SIGCOMM (2001) 20–41.
[28] http://www.alertsystems.org.
[29] J.M. Rabaey, M.J. Ammer, J.L. da Silva Jr., D. Patel, S. Roundy, Pico radio supports ad hoc ultra-low power wireless networking, IEEE Computer Magazine (2000) 42–48.
[30] K.K. Tan, S.N. Huang, Y. Zhang, T.H. Lee, Distributed fault detection in industrial system based on sensor wireless network, Computer Standards & Interfaces 31 (2009) 573–578.
[31] Mingni Shi, Development of water-quality remote dynamic monitoring system in aquaculture, China Agricultural University, 2008.
[32] Aqeel-ur-Rehman, Abu Zafar Abbasi, Zubair A. Shaikh, Building a smart university using RFID technology, Technical papers of International Conference on Computational Science and Software Engineering, 2008, pp. 641–644.
[33] Hou Zhen, Implementation scheme of underground wireless scheduling communication system based on WiFi technology, Xi'An University of Science and Technology, 2009.