WSN Node Applied to Large-Scale Unattended Monitoring

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(Received 10 January 2015; revised 10 May 2015; accepted 14 May 2015)

Abstract: Long-term and stable wireless sensor network (WSN) node's operation should be included in large-scale unattended industrial production. Here a kind of WSN node applied to multiple large-scale industrial productions is designed by analyzing WSN technologies and its multiple applications, and studying the node's practical operating environment. A new method for applying image-recognition technology realized initially by using plenty of expensive sensors is proposed to analyze video data. When the node is applied in such situations as unattended operation and field monitoring, solar power generator is adopted to provide energy for the node system by charging a battery. The communication between WSN and background monitoring center is realized by GPRS module, and the operation of node is managed by transplanting μC/OS-Ⅱ into the ARM7 kernel microprocessor. The results show that the WSN node designed in this paper can be applied to control information transmission of wild and unattended large-scale industrial applications with stable and reliable performance.

Key words: wireless sensor network (WSN); nodes; embedded system

CLC number: TP393 **Document code**: A **Article ID**: 1005-1120(2016)03-0386-09

0 Introduction

China has the largest scale of aquaculture in the world, and is the only country having more aquaculture production than fishing production, whose aquaculture production occupies more than 70% of the world's total aquaculture production every year. Freshwater aquaculture plays a significant role in China's aquaculture. Today, freshwater aquaculture has gradually become a new profit point of China's new-type rural economy, because of the low-cost labor market and huge potential of development. The aquaculture area of China is about 8 088.4 thousand hectare, and the freshwater aquaculture area covers about 5 907.48 thousand hectare, which accounts for 73.04% of the total area. Besides, numerous freshwater lakes exist in Jiangsu Province, and the sum of freshwater lakes is about 290. The total area of freshwater lakes in Jiangsu Province is about 6 853 km^2, and the ratio of the lakes in the total area of Jiangsu is about 6%, which is the highest in China. At present, the freshwater aquaculture area of Jiangsu Province is about 571.82 thousand hectare. In 2012 alone, the freshwater aquaculture production of Jiangsu Province reached 3.118 3 million tons.

Generally speaking, the water quality of aquaculture is one of the most important factors that determines the safety and production of aquaculture. And such main factors including dissolved oxygen, PH value, quantity of illumination, ammoniacal nitrogen, nitrate nitrogen, wind speed, water temperature, air temperature, air pressure, total hardness, salinity, quantity of plankton, and phosphorus, etc. influence the water quality by interaction, interplay and mutual transformation instead of independent effect. Ev-

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How to cite this article: Bao Yujun, Ji Changying, Chen Gong, et al. WSN node applied to large-scale unattended monitoring[J]. Trans. Nanjing U. Aero. Astro., 2016,33(3):386-394.
http://dx.doi.org/10.16356/j.1005-1120.2016.03.386

ery year in China, the economic loss of freshwater aquaculture caused by unnatural disasters, such as polluted water, reaches billions of Yuan. In the year of 2012 alone, the domestic economic loss concerning freshwater aquaculture caused by bad water quality reached 1.846 billion Yuan with 0.1 billion Yuan loss in Jiangsu Province. Meanwhile, the domestic freshwater aquaculture loss caused by fish diseases reached 3.614 billion Yuan along with 0.288 billion Yuan loss of Jiangsu Province[1]. In normal conditions, water quality is the main factor that influences the occurrence of fish diseases. Therefore, the water quality of freshwater aquaculture should be monitored with high reliability and efficiency, and then the aquaculture water will be adjusted by referring to these monitoring results. This is one of the most necessary measures to ensure the safety of freshwater aquaculture.

Wireless sensor network (WSN) is a kind of self-organized network by deploying plenty of sensor nodes in monitored area, and multi-hop transmission is accepted when data needs to be transmitted. WSN has been applied to freshwater aquaculture preliminarily, and some parameters representing the water quality are gathered by using water quality sensors which are connected with WSN sensor nodes. These gathered data are usually transmitted by WSN, and then some adjusting devices which are used to adjust water quality are started, which is conducive to achieving high production and efficiency in the freshwater aquaculture industry. Du[2] designed a kind of remote and real-time water quality monitoring system which realized the acquisition of water quality data and their transmission by combining WSN with the Internet. Huang[3] proposed another freshwater aquaculture monitoring system based on WSN, sensor nodes (also acted as router nodes), sink node (usually acted by sensor nodes through adding serial port circuit), local and remote monitoring center are included as well. In terms of indoor industrialization aquaculture, Yan[4-5] developed a intelligent monitoring system of freshwater aquaculture by combing RFID with monitoring system for aquaculture based on WSN to monitor aquaculture environment, water quality parameters, medicine usage, condition of fish growth, and wastewater treatment.

But some defects also exist in this method. Firstly, water quality sensor technology is not perfect, such important factors as dissolved oxygen, PH value, quantity of illumination, ammoniacal nitrogen, nitrate nitrogen, wind speed, water temperature, air temperature, air pressure, total hardness, salinity, quantity of plankton, phosphorus, which influence water quality for aquaculture cannot be fully measured. Secondly, the existed sensors for measuring water quality parameters are relatively expensive, and in the case, they cannot be applied to freshwater aquaculture on a large scale. Thirdly, the precision of water quality sensors is always degraded during their practical application, and the lifetime of these sensors is also relatively short. Fourthly, the gathered water quality data by using water quality sensors may be of one-sidedness, which cannot reflect the whole situation to some extent. Fifth, data fusion, topology structure, and WSN power cost are all seldom concerned in the present freshwater aquaculture WSN. In most cases, they are only acted as a tool used to transmit data remotely.

Many important parameters of water quality are accepted as monitoring targets, and a new WSN control node employed in large-scale unattended monitoring is designed. Extra electric supply is unnecessary to this node, because solar power generation is accepted and provided to the node system by charging the battery, which expands its scope of application and extends its lifespan. Wireless communication of remote monitoring is realized by embedding GPRS module which is in favor of the communication between WSN and background monitoring center. The stability and reliability of node system is enhanced by transplanting μC/OS-Ⅱ into ARM7 kernel Microprocessor. WSN which monitors many important parameters of water quality in wide water-area can be structured by introducing this type node in a large quantity, which is conducive to achieving real-time collection of water quality parameters, wireless transmission and remote monitoring.

1 WSN Construction of Large-Scale Freshwater Aquaculture

Such modern technologies as computer vision process and ultrasonic are gradually applied in the research of fish behaviors[6-7]. The relations between fish behaviors and water quality can be reflected by depending on these modern technologies, and then a water quality forecasting model can be built based on these studies. Therefore, the aquaculture water quality can be adjusted intelligently and automatically by the constructed freshwater aquaculture WSN in order to keep the water quality in the optimal condition. Plenty of water quality sensors are not included in this method, which reduce the cost significantly. Thus, it is a cheap and reliable method for large-scale freshwater aquaculture. In this case, WSN does not work as the transmission medium of water quality data but is adopted to transmit control information from monitoring center to such water adjusting devices as water purifying device, heating device, oxygen adding device, etc. The control information about casting bait is also transmitted by the WSN. Besides, the WSN is able to reflect the operating state parameters of these devices (such as the bait casting type, the quantity of casted bait, the current water temperature, etc.).

Fig. 1 shows the whole freshwater aquaculture system based on fish behavior and WSN technologies. The aquaculture plant is divided into several aquaculture areas based on WSN. A video data acquisition device is included in every aquaculture area to monitor fish behavior. Water quality of current aquaculture areas can be forecasted by the developed control algorithms. A sink node and several control sensor nodes are also included in every aquaculture area to form a WSN. The sink node is powered by the solar power, and the sensor nodes include bait casting control node, water purifying control node, water heading control node and oxygen adding control node, etc[8]. Moreover, every aquaculture area is divided into three layers logically, namely, Sensing Layer, Network Layer and Management Layer. The relative sensors connected with control nodes are in the Sensing Layer, which is used to show the current state of those nodes; the wireless communications between these control nodes and sink node are involved in the Network Layer. In order to ensure the homogenization of bait

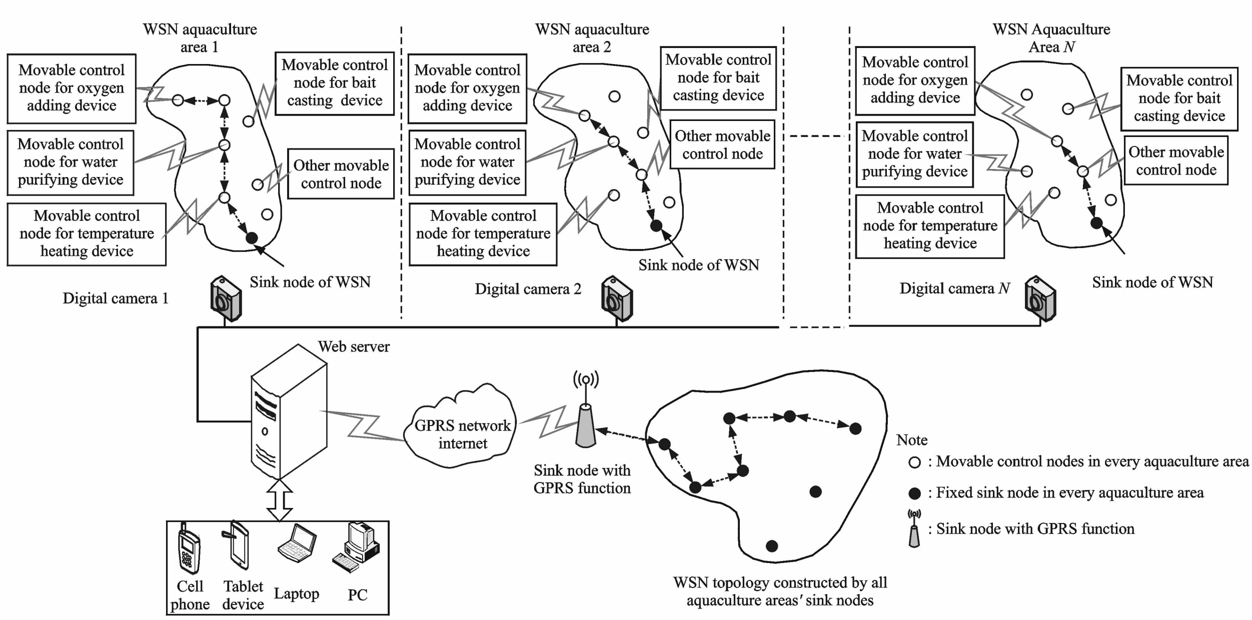

Fig. 1 Freshwater aquaculture system based on fish behavior and WSN technologies

casting, water purifying, water heating and oxygen adding, the position of all control nodes in every aquaculture area changes every now and then. And all the sink nodes' positions are fixed, but the data transmission topology is not. In some ways, these sink nodes are acted as backbone network of data transmission. The chosen sink node with GPRS function is used to transmit data from WSN to monitoring center, and vice versa[9]. In order to guarantee the reliability of data communication and prolong the lifecycle of WSN, GPRS module is configured and proper algorithms are designed in every sink node, so the overdependence on one sink node can be avoided. Users can login freshwater aquaculture monitoring system platform in web server by using their cell phones, tablet devices, PC, etc. to monitor the area's water quality.

Freshwater aquaculture is one part of large-scale agriculture. By monitoring fish behavior to forecast the water quality, improving the current freshwater aquaculture WSN, and combining artificial intelligent system with relative instruments, meters, such automatic managements as purifying water, heating water, adding oxygen, casting bait and fishing can be all accomplished by using computer intelligent control, which reduces the cost of human resources and material resources, and is of great importance for enhancing intelligence of freshwater aquaculture and precise management.

The large-scale freshwater aquaculture system is mainly deployed in remote field to control the operation of strong current devices (such as water pump, electrical motor), which effectively solves the power supply problem of the control node in a long period. While every sink node in aquaculture area needs to undertake the data transmission task from local WSN to monitoring center in a long-time operation period. Thus, a stable power supply is indispensable for sink node. In addition, considering the bad environment, some measures should be taken in order to ensure the reliability of WSN communication.

2 Design of WSN Sink Node to Monitor Water Quality Parameters

WSN control node design applied to large-scale freshwater aquaculture is proposed in this paper. As a sink node, solar energy power is used to keep its normal operation. Therefore, the node can operate for a long period reliably and stably. GPRS module is also included in sink node, which can realize the WSN data's remote transmission[10]. Whether control node or sink node, Zigbee chip CC2530, data acquisition circuit for node's state parameters and WSN wireless data communication module are all combined together. ARM7 kernel Microprocessor S3C44B0X is adopted to further analyze and process the gathered data because of the inner 51 kernel's poor data procession of CC2530 chip. Moreover, a new type of power supply device with solar energy based on S3C44B0X is involved in the node design.

The structure of WSN sink node applied to large-scale freshwater aquaculture is shown in Fig. 2. CC2530 chip, launched by TI Corporation, is a new type chip installed on Zigbee. Standard 8051 Microcomputer kernel is embedded

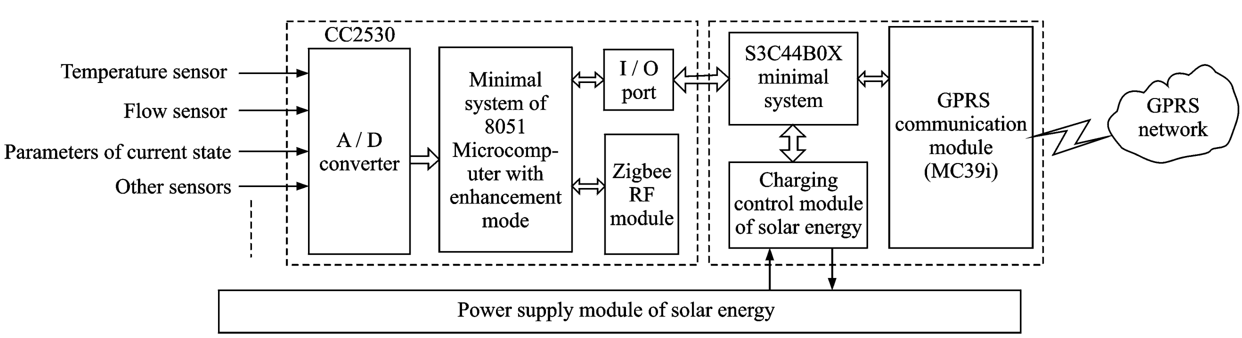

Fig. 2 Structure of WSN sink node applied to freshwater aquaculture

in this chip, and it is fully compatible with IEEE 802.15.4 standard protocols. RAM, ROM, A/D converter, SPI communication bus, wireless RF module and other functional modules are all incorporated together, which is helpful to simplify the hardware design, and the power cost of wireless communication can be reduced tremendously[11-12].

To the normal WSN control nodes, all kinds of collected parameters can be converted by an inner A/D converter of CC2530 chip, and then be processed initially. Communication between nodes is realized by the inner Zigbee RF module. To the sink node, ARM7 kernel Microprocessor S3C44B0X is used because of CC2530 chip's limited ability of data procession. The local WSN data can obtain further processing, and then be transmitted by using GPRS module (MC39i), which tends to realize the WSN data's remote transmission. Solar power generation and charging the battery are both accepted in sink node, which ensures the stable power supply. It should be noticed that the total solar charging process is controlled by S3C44B0X.

2.1 Design of node power conversion circuitry based on solar energy

For the situation that the whole power cost of WSN sink node used in remote large-scale freshwater aquaculture is not very high, the design of solar power supply is adopted. Lead-acid battery (12 V/20 AH) with the characteristics of high performance and simple maintenance, and 18 V/20 W solar energy battery panel (410 mm × 340 mm × 18 mm) are used, which can satisfy the power need of WSN node operating in remote area in a long period. After conversion, the output voltage of solar battery panel should not be used to supply the node directly, because the battery's voltage rating is 12 V. Therefore, DC-DC converter is accepted, and the photovoltaic output voltage is converted to the battery's voltage rating (12 V) by using the mode of step-down charging. The stable and acquired DC voltages that the node system needs in various amplitudes are further converted from power converter chip. The control circuit of power conversion is shown in Fig. 3.

In Fig. 3, R1 is a piezoresistor used to prevent solar photovoltaic panel from being destroyed because of potential instant high voltage. R2 is a fuse with self-recovery function, and it has the function of overcurrent protection to prevent battery from being destroyed when short-circuit occurs. The circuitry of step-down charging is BUCK type. Ripple factor and dynamic effect should be considered synthetically when the value of energy storage inductor L is determined. The

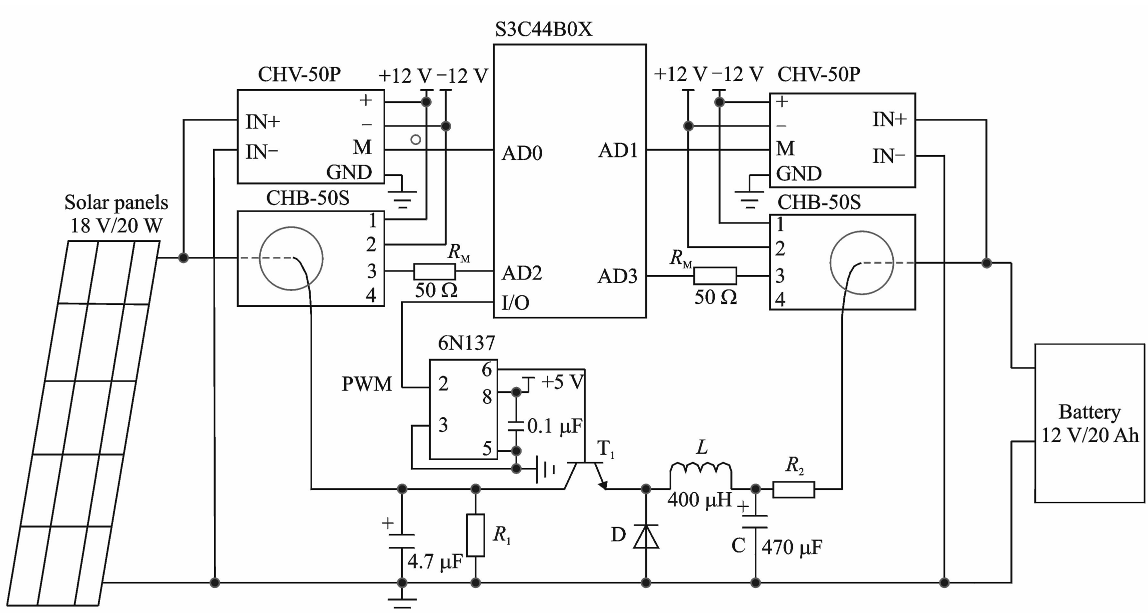

Fig. 3 Power conversion circuit of solar energy applied to node system

critical value of inductor L_C should be determined firstly by using the formula $L_C = \frac{U_0(1-D)}{2I_0 f}$. In this formula, the value of duty cycle D is determined by $D = \frac{U_0}{U_m} = \frac{12}{18} = 0.67$; and the value of frequency f equals 10 kHz; the value of output current I_o equals 1 A. So the calculated value of L_C is 198 μH. The value of filter capacitor C is determined by the formula $C = \frac{U_0(1-D)}{8Lf^2 \Delta U_0}$, where ΔU_0 is the output ripple voltage whose value is 0.5% of output voltage. So the calculated value of C is 206 μF. When storage inductor and filter capacitor are applied to practical circuits, their real values should be twice as big as the calculated critical values of inductor and filter capacitor respectively. Therefore, the applied value of L is 400 μH and C is 470 μF.

In order to know and control the operation states of solar energy battery panel efficiently, two groups of closed loop hall current sensor CHB-50SE (the value of sampling resistor RM is 50 Ω, so the resistor's voltage 5 V is corresponding to "Input current 50 A and Output current 100 mA") and hall voltage sensor CHV-50P (the output voltage of 1 V is corresponding to the input voltage of 10 V) are applied to sample solar energy panel's output voltage, current and output voltage and charging current of lead-acid battery, respectively. The acquired samples are then processed by S3C44B0X Microprocessor. Four ten-digit A/D converters (AD0-AD3) in S3C44B0X Microprocessor are used to convert samples directly, because those four signals are almost entirely DC signals with slow changes, so the cost of hardware is saved. Photoelectric coupler 6N137 in Fig. 3 is used to insulate S3C44B0X Microprocessor's output control signals and drive power switch device T1, so both the system's anti-jamming ability and stability can be increased.

Nowadays, there are WSN node designs with multiple purposes, and its node power consumption (directly related to its lifetime) is the main research direction. The method of hibernate is commonly adopted. No matter what scheme and algorithm are accepted in the node's hardware and software design, the built-in power energy will be exhausted without extra power supply. The power design proposed in this paper prolongs the node's lifetime efficiently by combining some algorithms about energy management. While the node entering hibernate mode, the solar panel can still charge the built-in battery, which keeps sufficient energy of the node.

2.2 Design of GPRS communication module interface circuit in sink node

The interface circuit between S3C44B0X Microprocessor and MC39i, the GPRS wireless communication module is shown in Fig. 4. Standard RS232 interface with nine-pin is included in MC39i module, and SP3232 chip is accepted to convert electrical levels when the data communication happens between MC39i module and S3C44B0X Microprocessor, and the operation mode is full duplex. MC39i module is connected to the Internet by PPP protocol before the MC39i module sends data. In TCP/IP protocols, point to point (PPP) protocol is included in data linker layer, which is used to transmit data packets between two peer-to-peer network terminals. The operating steps are shown in brief. Firstly, data link is built by using link control protocol (LCP), and then it is configured and tested. Secondly, different Network layer protocols are created and set up by using network control protocol (NCP). Generally, all kinds of parameters' configurations including working frequency of the MC39i module are performed after sink node's first initialization. And then the PPP negotiation between the MC39i module and the mobile station is performed by dialing, and the operation of GPRS module's connecting to Internet is finished after getting local IP address distributed by mobile operator.

The MC39i module is controlled by S3C44B0X using attention (AT) commands after the MC39i module successful dialing and connecting to the Internet. In upstream communication link, when MC39i module is used to transmit data, the whole process is performed by serial port, which is controlled by S3C44B0X Microprocessor. The necessary transmitting data of sink node are firstly processed by TCP/IP data-format (Data are encapsulated IP format packets), which is performed by S3C44B0X. Then these IP packets are converted into GPRS packets and uploaded GPRS network, which is controlled by the MC39i module. In a downstream communication link, IP data packets are extracted, and the control information is acquired by processing these IP packets. And the whole process is performed by S3C44B0X. The flow chart represents the connecting process of GPRS module, and the negotiation process of PPP is shown in Fig. 5[13].

3 Realization of Embedded TCP/IP and Transplant of μC/OS-Ⅱ in S3C44B0X

Four layers are included in TCP/IP protocols and various and numerous complicated network protocols are included in every layer. TCP/IP protocols should be simplified in S3C44B0X Microprocessor because only basic data transmission is required in WSN sink node. Some key and basic protocols[14] (such as PPP, ARP, UDP, TCP, IP, etc.) are kept, and the simplified protocols are shown in Table 1.

The entire system is managed by transplanting embedded operating system to microprocessor, which has become the trend of embedded system development. As a sink node, although 8051 microprocessor is embedded in CC2530 chip, its processing ability is very limited, which prevents it from undertaking such tasks as data acquisition, data conversion, data communication between nodes, WSN data analyzing, realization

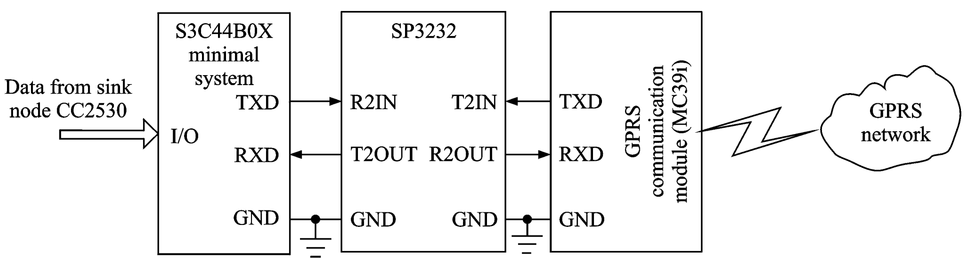

Fig. 4 GPRS module of communication control

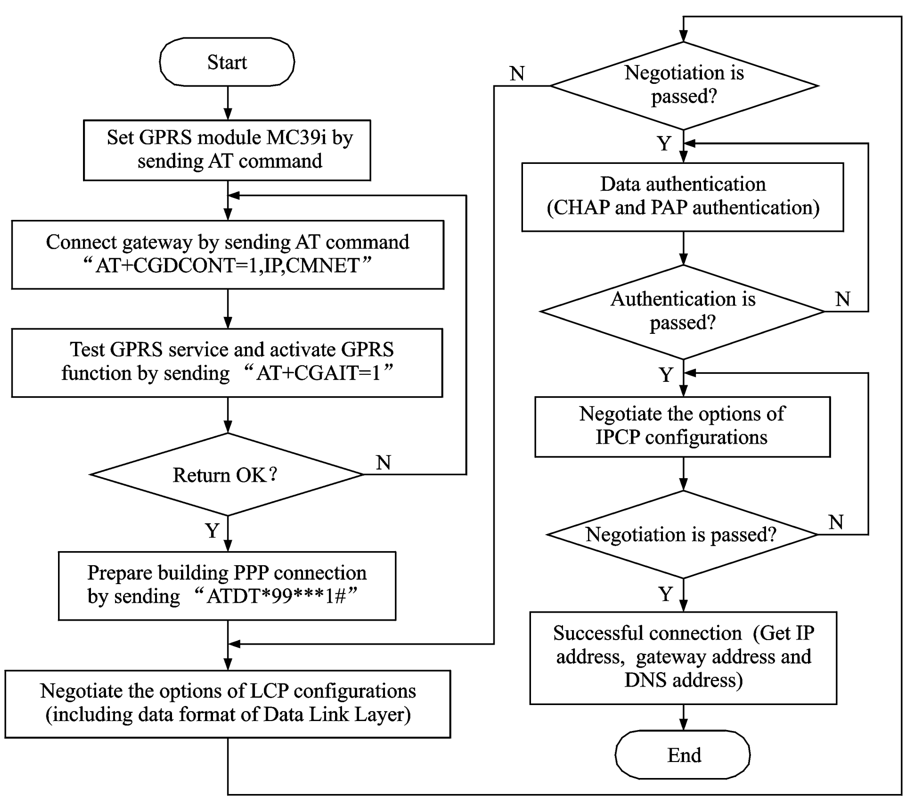

Fig. 5 Connecting process of GPRS module and negotiation process of PPP

Table 1 Main difference between standard TCP/IP protocols and simplified TCP/IP protocols

	Standard TCP/IP protocols	Simplified TCP/IP protocols
Application layer	Almost all protocols of application layer can be realized at the same time.	According to the users' needs, protocols of application layer are simplified.
Transport layer	The safety and reliability of data communication can be ensured by several mechanisms in TCP/IP	The connection and disconnection modes of "Three-time handshake" are simplified. Such mechanisms as traffic control, congestion control, etc. are omitted, and the safety of data communication only depends on the performance of network.
Network layer	The maximum data capacity of the IP packet can reach 65 KB, and the IP packet can be segmented and reassembled.	Segmented and reassembled transmission is not permitted, and the 65 KB size IP packet is unable to be accepted.
Network interface layer	Virtual memory is adopted, and memory's management and allocation are finished by Operating System, without considering the size of memory.	Without any memory management mechanism, the capacity of data receiving buffer is limited, and the addresses are all fixed. Generally, Socket functions should be developed by users to realize communication.

of simplified TCP/IP protocols and operation of GPRS module well at the same time. The whole operation of sink node has excellent real-time performance and reliability by transplanting embedded operating system μC/OS-Ⅱ into S3C44B0X microprocessor. Both sink node's operation and host-guest communication mode (S3C44B0X and CC2530) run well because of μC/OS-Ⅱ.

According to the structure characteristics of S3C44B0X Microprocessor, some codes are developed by using assembly language, so the relevant registers of S3C44B0X can be operated. Definitions of data types which have no relations with compiler, and the definitions of stack's data type and its increasing direction are all included in the file OS_CPU. H. Task initialization program of μC/OS-Ⅱ is included in the file OS_CPU_C. C. Key programs, such as the system clock interrupt function, task switch function, etc., should be developed by assembly language and included in the file OS_CPU_A. S[15].

4 Conclusions

Domestic and foreign research on water quality sensors being used to acquire one or several water quality parameters and forecast water environment is found frequently, and the domestic freshwater aquaculture WSN as data transmission tool with single function is not the real WSN. In order to guarantee the safety and reliability of freshwater aquaculture, fish behavior data acquired from video devices are used to analyze and forecast aquaculture water quality. Besides, the water quality adjustment information can be transmitted by WSN. Adding freshwater, controlling temperature, adding oxygen, casting bait and other measures can be taken by computer intelligent control technologies, which realize the automatic management of freshwater aquaculture. Users can know the water environment by using PC, cell phones, tablet devices, etc. to decrease the investment of human resources, material resources as well as economic losses caused by personal errors, which is of great significance to improve the intelligent degree of freshwater aquaculture.

A kind of WSN sink node applied in large-scale freshwater aquaculture is designed, and its hardware design is emphasized. In addition, solar power supply is adopted to charge the battery considering the node's practical working conditions, which solves the power consumption problem (it determines the lifespan of the whole node system). Finally, the result shows that the designed WSN sink node can operate in remote freshwater aquaculture environment with high efficiency and good performance. Meanwhile, the design in this paper may be instructive to other designs concerning WSN monitoring.

Acknowledgements

This work was supported by the Cooperative Innovation Fund of Industry-Study-Research of Jiangsu Province (No. BY2013074-03), the Key Laboratory of Underwater Acoustic Communication and Marine Information Technology Ministry of Education, the Natural Science Foundation of Changzhou Institute of Technology (No. E3-6107-15-037), the Student Innovation Training Program of Jiangsu Province (No. 201611055019Y).

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