

Design of Real-time Monitoring System for Aquaculture Sea-cages with GPRS and Embedded Systems

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Abstract: Many things are adversely affecting the seas and oceans to satisfy demand for fish consumption worldwide. As a result, aquaculture is growing fast in the food-producing sector.

In a view to maximizing their potential, managers of aquaculture production facilities need reliable, real-time reports on system status and performance. In this project, we developed a low-cost, low-power remote monitoring system for open-sea aquaculture cages, based on GSM (Global System for Mobile Communications) and Embedded Systems to monitor an open-sea aquaculture system in real time, for ideal and adequate fish growth environments.

The Open-Ocean Aquaculture at the AquaMdiq Company currently uses 14 fish cages to raise finned fish in the open ocean. The cages are located about five miles offshore, making regular monitoring both expensive and time-consuming. Specialists and aquaculture agriculturists thus require a way to investigate aquaculture temperature, dissolved oxygen, and pH remotely every day without actually visiting the pens, and in the long run, to control the sustaining and maritime operations by observing remotely.

Our objective is to develop a real-time, accurate and fast monitoring system that can take over the role of the eyes and hands of an aquaculture farm worker.

The main features are arranged in two parts: aquaculture cage monitoring station, and remote monitoring centers. The monitoring station measures the seawater temperature, dissolved oxygen, and pH through the sensors, and consists of a remote data-collection terminal and intelligent water sensors, by which the temperature, dissolved oxygen, and pH of the seawater is measured in real time, processed online and transferred via a GPRS wireless network.

The remote monitoring centers connect the central server using the Internet. The seawater water data are communicated to the central server via GPRS wireless networks.

Keywords: Aquaculture cages, GPRS, Remote monitoring, Embedded system.

1. Introduction

Aquaculture is the fastest growing food sector in the world, with an average annual growth rate of 8.9 % since 1970 [1].

Fish farming can be carried out wherever water is available, with some species even able to adapt to brackish/saline waters. The only major constraint is thermal: 15 °C minimum to 38 °C maximum (optimum: 28–32 °C).

Automatic remote monitoring and computer-controlled intensive cultivation is the future trend of open-sea aquaculture. In the management of modern aquaculture, the monitoring of water quality plays an important role.

Appropriate water temperature monitoring to maintain the water environment parameters in the optimum range can improve the growth rate of fish and the impact on food utilization, and may reduce the frequency of large-scale fish diseases [2, 3].

That is why we need to control this environment and do real-time follow-up and timely interventions to minimize any damage.

Aquaculture is a resource-rich place that requires technologies such as real-time monitoring, data collection, storage and analysis of various growth environments for these resources, but there are very few applications and development cases in the marine environment even though the development value is very high.

In this paper, we introduce a real-time monitoring system for aquaculture sea-cages with GPRS and Embedded Systems.

Fish reproduction will be managed by a computer system considering all appropriate studies in this area.

This system is a combination of GPRS communications technology, an embedded system and aquaculture cage remote monitoring, which make up for the need for traditional aquaculture-cage monitoring. The central server interacts with the aquaculture cage monitoring station and transfers the data stream to the remote centres, to achieve a wireless-remote-monitoring function, with which it is able to get the real-time seawater temperature, dissolved oxygen, and pH.

2. Related Works

Remote monitoring systems have received significant attention in offshore aquaculture because migratory fish species such as tuna and mackerel are raised in offshore aquacultures to overcome the low productivity of inshore aquaculture. Several researchers have developed remote monitoring systems.

Some used Sensor Network technologies that are the foundation of IoT (Internet of Things) [4-6]. In general, each node on the ground uses a radio frequency (RF) for communication and sonic communication in water [7, 8].

The authors studied a centralized remote monitoring system for an offshore aquaculture cage farm in [9].

The proposed system consists of a central server, a remote monitoring center and a seawater monitoring station, which includes a node controller and a GSM data-transmission unit, and sensors. They described the transmitter system as able to monitor a group of cages and only took several seconds to scan a cage. As far as we know, there is no system in existence similar to our proposal.

The battery power used by ocean sensor networks is limited. That is why the seawater monitoring station is optimized, using low power and low-cost wireless communication technology.

3. Main Structure of the System

The core objectives of the system are usually devoted to the monitoring of open-sea aquaculture cages.

Experts and aquaculture farmers need a way to remotely inspect aquaculture temperature, dissolved oxygen, and pH on a daily basis without visiting the cages themselves and, in the long run, need to be able to control the feeding and offshore operations remotely.

Our objective is to develop a real-time, accurate and fast monitoring system that performs the role of eyes and hands of an aquaculture farm worker.

Decisions should increase productivity, ensure quality and optimize the use of resources and resources. Those are main feature of our system:

- Inform about the state of the seawater temperature, dissolved oxygen, and pH: correlation with the standard process of evolution.
- Identify the need for fish: according to the appropriate development plan.
- Identify malfunctions: deviations from the scheme and corrective measures to be taken, deviations from normal states and relevance.
- Provoke a critical reflection which is not limited to the available means, but integrates the sense of intervention in time.

The principle of operation of the system can be shortened to the following points:

- The owner receives notifications in real time (via mobile or desktop), to make a decision.
- Notifications arrive in the form of services (not just SMS messages).
- Propose an adequate guide according to the situation.
- Direct interventions in the field with coordination between employees in the field.

To accomplish the above functions, we design a real-time seawater temperature, dissolved oxygen, and pH monitoring system that includes a seawater monitoring station, central server, remote monitoring center, as shown in Fig. 1.

The seawater monitoring station collects seawater temperature, dissolved oxygen, and pH at different depths and then sends the data to the central server via GSM wireless networks.

The monitoring centre obtains the regularly updated central server via the Internet and then provides the function of data presentation, data storage and data download.

The following subsections provide a detailed explanation of the components of our remote monitoring system.

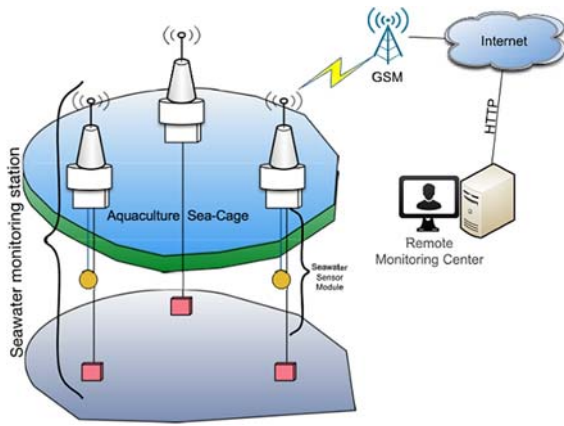


Fig. 1. Main structure of the system.

4. Hardware Design and Working Principle of Seawater Monitoring Station

The seawater monitoring station links the sensor module installed under the fish cages and a monitoring centre on land. Thus, it is deployed on the fish cages and performs data transmission between the sensor module and the remote monitoring centre. To achieve this, the seawater monitoring station requires two modules: a GSM communication module; and a sensor module. We use the GSM module for data transmission between the sensor module and the monitoring centre, and the sensor module to measure the environmental data of the sea-cage.

To explain our developed seawater monitoring station, Fig. 2 presents a block diagram of the seawater monitoring station. As shown in Fig. 2, the seawater monitoring station is composed of an MCU (microcontroller) module, a GSM communication module and a sensor module.

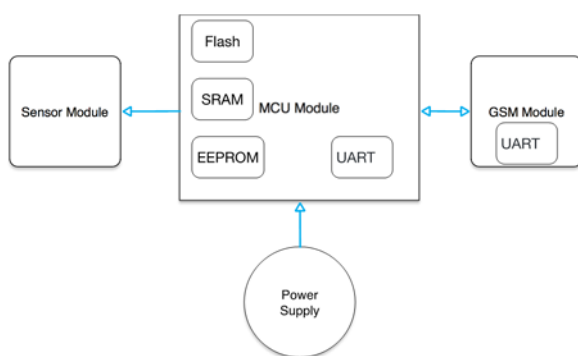


Fig. 2. Block diagram of the seawater monitoring station.

First the sensor module is connected to the microcontroller that collects data measurement to back them up in internal storage, or send them via the GSM module to the remote monitoring centre. Second, the seawater monitoring station uses USART ports as an interface for the GSM communication module.

The seawater monitoring station is responsible for processing the sensed data from communication interfaces and sending it via a GSM module via wireless network transmission. This monitoring station assumes an essential part as it collects and transfers information, and manages power management through the sleep/awake modes of the microcontroller and the GSM module.

Considering the project requirements related to cost, stability, accuracy, durability and other indicators, we chose the following components for the system:

- ATmega328: the most common microcontroller due to its low power consumption, several sleeping modes, flash memory, efficient byte-orientated storage and low price. Its current consumption on active mode is 4.74 mA, its idle mode is 0.9mA, and sleep mode is 0.5 1A, making it appropriate to maintain extended battery life at the seawater monitoring station

- GSM module SIM800L [11] is a quad-band GSM/GPRS module, that works on GSM850MHz, EGSM900MHz, DCS1800MHz and PCS1900MHz frequencies, and has a low price and very low power consumption.

MCU module.

The microcontroller for the seawater monitoring station is an ATmega328 it an 8-bit AVR microcontroller (see Table 1), which has 32 kB of flash memory for caching code (of which 0.5 kB is handled for the bootloader), has 2 kB of SRAM and 1kB of EEPROM (which can be read and written with the EEPROM library) [10], and operates using a 3.3 V power supply, see [13].

In general, a microcontroller is better suited than a microprocessor to anything that requires sensing of inputs.

A program is loaded into the microcontroller over a serial connection or USB connection from a PC via the 'bootloader' program.

Table 1. ATmega328 features.

Microcontroller	ATmega328
Board Power Supply	3.35 – 12 V (3.3 V model) or 5 – 12 V (5 V model)
Circuit Operating Voltage	3.3 V or 5 V (depending on model)
Digital I/O Pins	14
PWM Pins	6
UART	1
SPI	1
I2C	1
Analogue Input Pins	6
External Interrupts	2
DC Current per I/O Pin	40 mA
Flash Memory	32 KB of which 2 KB used by bootloader
SRAM	2 KB
EEPROM	1 KB
Clock Speed	8 MHz (3.3 V versions) or 16 MHz (5 V versions)

The microcontroller is powered by a battery installed in the buoy, with a waterproof system for long-term maintenance and high autonomy.

Sensor module.

The sensor module is installed above the buoy at different depths, and contains different waterproof sensors to measure temperature, dissolved oxygen, and pH. This sensor module is attached to the anchor cable to ensure the stability of the measurements.

GSM module.

Fig. 3 shows a functional diagram of SIM800L:

- GSM baseband;
- GSM RF;
- Antenna interface;
- Other interfaces.

The power supply range of SIM800L is from 3.4 V to 4.4 V. The peak power of the GPRS (General Packet Radio Service) module is just 2 amps in the network-

initialization phase, so the power module must provide a current of more than 2 A for the GPRS module.

The SIM800L can be powered down by pulling down the PWRKEY (power key) for at least 1 second and releasing it. But to power down the GSM module remotely it is possible to shut down the module by the microcontroller when not transmitting data.

In sleep mode, the SIM800L module's power-saving technique enables it to consume as little as 0.7 mA.

Usually, most electronic products with good performance are based on good PCB (printed circuit board) layout. A bad PCB layout will lead to lots of issues, like TDD noise (Time Division Distortion), SIM card not detected etc. Based on the above principles, the recommended layout is shown in Fig. 4.

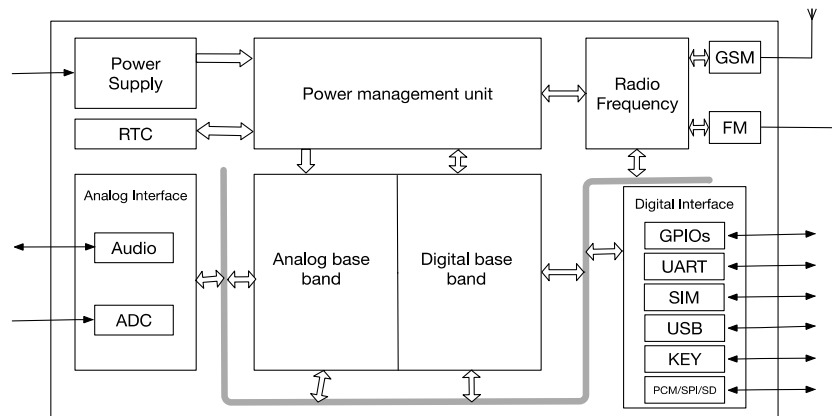


Fig. 3. SIM800L functional diagram.

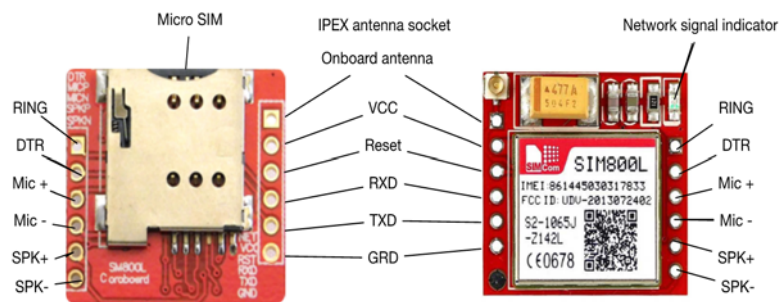


Fig. 4. Recommended PCB layout of the GSM module SIM800L.

The module tolerates a maximum voltage of 4.4 V on VCC (positive power supply pins) from a 'strong' power source and needs up to 2 A peak power. With a 5 V power supply, we need a simple resistor voltage divider, as shown in Fig. 5.

The simple 3.7 V Li-ion cell battery can be connected to the SIM800L power supply pins directly, because it is in the power supply range of SIM800L from 3.4 V to 4.4 V. In this case, we don't need the resistor voltage divider.

The voltage of the UART (universal asynchronous receiver/transmitter) interface of our MCU module is 3.3 V, whereas most of the SIM800L sellers claim it to be 5 V tolerant. However, the hardware design manual specifies the maximum voltage to be 2.8 V for the UART interface of the SIM800L. To follow the design manual guidelines, we use another resistor voltage divider. The following reference circuit is recommended Fig. 6.

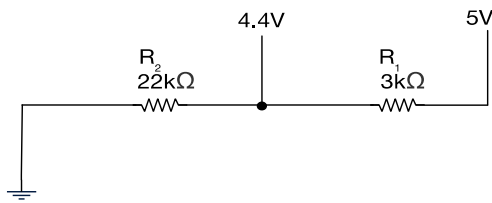


Fig. 5. Resistor voltage divider for 5 V power supply.

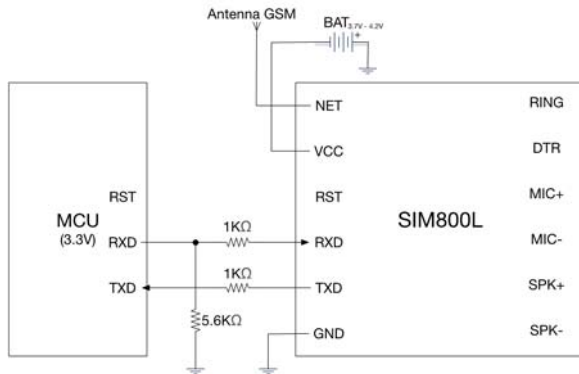


Fig. 6. Resistor divider matching circuit for the UART communication interface.

The SIM800L module can put errors as unsolicited messages on the TX line, or just not work correctly. This module has a Reset pin used to reset the module. This option is used only when we cannot communicate with the module from the microcontroller, or we cannot power the recommended circuit on the module to reset the module from the microcontroller, as follows Fig. 7.

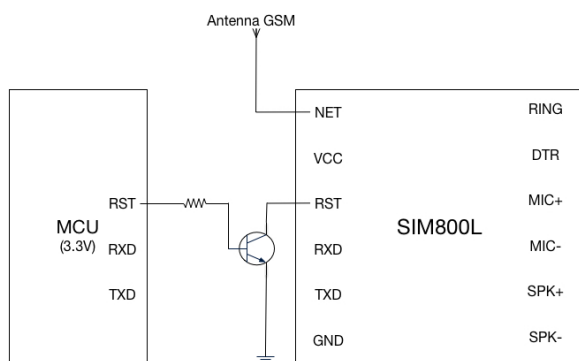


Fig. 7. Reset circuit.

Apart from errors, the blinking pattern of the network status indication LED can help to identify the status of the module and possible problems (Table 2).

Power module.

Fig. 8 shows the design of our power module system that will generate power for the seawater monitoring station and make it self-powered. It will convert tidal stream energy from the sea current into electrical energy and store it in the storage battery.

It is composed of five components:

- Helices that contain 3 blades made to rotate with a weak sea current;
- Gear box for 90° transmission and multiplier;
- Low rpm generator 12 V, 2 A with min 120 rev/min;
- Battery storage;
- Charge controller.

Table 2. Status of the network status indication LED.

Status	SIM800L behaviour
Off	SIM800L is not running
64 ms On/800 ms Off	SIM800L not registered to the network
64ms On/3000ms Off	SIM800L registered to the network
64ms On/300ms Off	GPRS communication is established

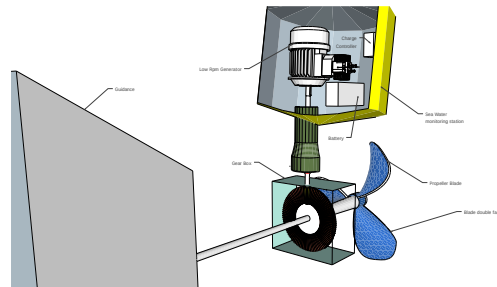


Fig. 8. Cross section of the power module.

As shown in Fig. 9 the sea current flow rotates the helices and with bevel gears we have a 90° transmission. This rotation is transmitted to a waterproof low RPM generator inside the seawater monitoring station and generates an electrical power. With a regulator it will charge the battery, which will supply power to the whole system.

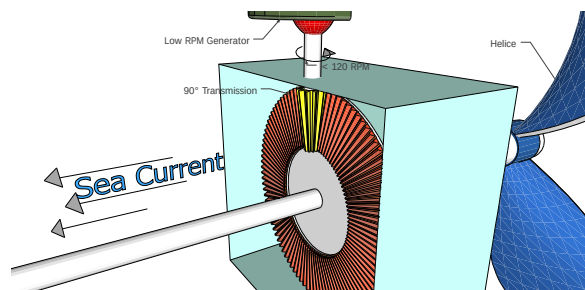


Fig. 9. Bevel Gears box for 90° transmission and power multiply.

Our low RPM generator can reach 12 V and 2 A for charging at 120 rpm. To accomplish this speed of revolution per minute, we used a bevel gear that

gives a 90° transmission and multiplicity of power. As shown in Fig. 10 the DRIVER gear with 100 teeth is larger than the DRIVEN gear with 10 teeth. As a general rule, large-to-small gears multiplies the velocity ratio by the rpm of the first gear. This rule is presented in the following equation:

$$\text{Gear Ratio} = \frac{\text{driven}}{\text{driving}} = \frac{10}{100} = \frac{1}{10} = 1:10$$

So, if the tidal power turns the driver gear at a speed of 12 RPM, with a gear ratio of 1:10 we get 120 RPM from the driven gear, which is largely sufficient to run our low RPM generator and reach 12 V and 2 A for charging our battery.

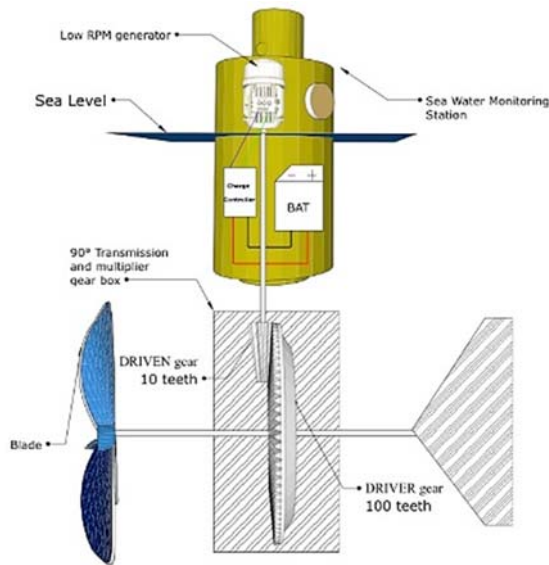


Fig. 10. Layout View of the full power module.

With this system, we can get 12 V and 3 A from 120 rpm, which is reached if the blades turn as slowly as 12 rev/min and that is very achievable considering the speed and power of the tidal sea.

The GSM module needs a high peak current of 2 A when connecting to the network. The design of the power module includes a 12 V DC to 3.7 V DC stepdown converter with a steady 3 A current LM2596, to power the GSM module, and a TPS79533 single output LDO with a fixed voltage (3.3 V) to power the MCU. See Fig. 11.

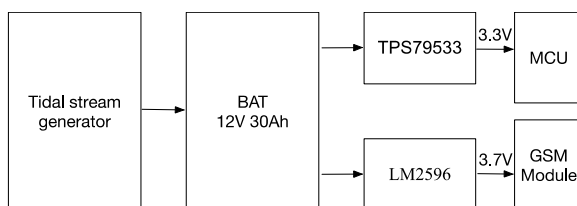


Fig. 11. Power module circuit for MCU and GSM module.

5. Hardware Design and Working Principle of Remote Monitoring Center

The monitoring centre is created on a notebook computer with a fixed IP address connected to the Internet (see Fig. 12). Thus, to construct the remote monitoring system, the IP address is known to the seawater monitoring station in advance. The environmental data sensed in the fish cages are transmitted to the IP address of the monitoring centre through the GPRS network, and are then processed and saved in the remote monitoring centre. Finally, the results are shown to users through a visual display.

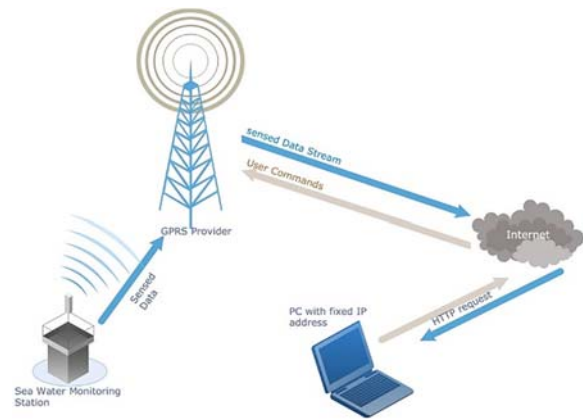


Fig. 12. Remote Monitoring Center.

The data shown in the remote monitoring centre must be obtained for every fish cage and transmitted to the monitoring centre.

Therefore, the developed system needs to operate at low power to maintain long-time autonomy. According to this requirement for the low-power operation of our system, the data transmission to the monitoring centre through GSM communication must be divided into intervals, so we can shut down the GSM module and put the seawater monitoring station into hibernation when not transmitting data. Thus, our system is based on a low-power operation and low-cost realization compared to the system where every fish cage transmits the sensed data to the monitoring centre on land without data-transmission management over time.

5.1. Software Design

Considering the project requirements for low power consumption we developed a framework to handle data sensing, which is optimized for low power consumption, which makes the monitoring system operate in two modes: normal mode and sleep mode.

Our remote monitoring system based on ocean sensor networks obtains environmental data remotely from offshore aquaculture cages and displays the collected data to the monitoring centre. For this work, we need data-transmission protocols to deliver the sensed data to the monitoring centre. To accomplish this, we have independently developed a firmware-based software system that includes GPRS transmission, which is embedded in the seawater monitoring station MCU module. In addition, we have constructed a management Database to manage the seawater monitoring station and the sensor modules deployed on the fish cages.

The GPRS transmission of seawater parameters (the key of the system software design) adapts a TCP protocol for data communication. The TCP protocol, a connection-orientated protocol, must first establish a connection before sending or receiving data. At the monitoring point, the user should configure related AT (attention) commands for GPRS module before it is used for the first time.

The configuration included setting the connection mode of the module, the communication baud rate, domain name and port etc. If the settings were all successful, then the GPRS module and the server will establish a TCP connection. The MCU module can send the seawater parameter data to the server through the UART interface, whereas the server can also send control commands to the seawater monitoring station.

The GSM module communication task is to set up the GPRS network and communicate with the remote monitoring centre. The GSM module is controlled by the MCU module through the UART interface using AT commands.

There are 10 GPRS states for the GSM module Fig. 13, and after every AT command sent to the module the state changes. The first state is the GPRS initial status to establish data connectivity, and the APN (Access Point Name), username and password need to be set in the second state. The third state starts a wireless connection with the GPRS. This sets up the wireless GPRS connection with the service provider and obtains an IP address. The fourth state change the GPRS context become active. The fifth state has an IP address assigned to the module after successful connection with the above commands. In the sixth state a TCP connection is made with the website on port 80. The first 'OK' is a response to command acceptance, and the second for a successful connection which is the seventh state. We can get into the eighth state by closing the TCP/UDP connection. If the connection is closed successfully then we are in the ninth state. In the tenth state, the context is deactivated.

To explain our developed seawater monitoring station, Fig. 14 shows the flow diagram of the seawater monitoring station software.

First, the MCU power the sensor module collects data for temperature, DO and pH and then shuts down. Then, to transmit the collected data, the GSM communication module is utilized. After the initialization of the system, data transmissions are

performed by operating the GSM communication modules. The time interval for data transmission is 30 min. The specific procedures are as follows.

1. By turning on the equipment, the entire remote monitoring system and GSM communication module are initialized, whereby the whole remote monitoring system includes the sensor module, seawater monitoring station and remote monitoring centre.
2. After all the initializations are successful, the constituents of the entire remote monitoring system achieve wired and wireless connections with each other; that is, the sensor module connects to the seawater monitoring station, and the seawater monitoring station connects to the remote monitoring centre.

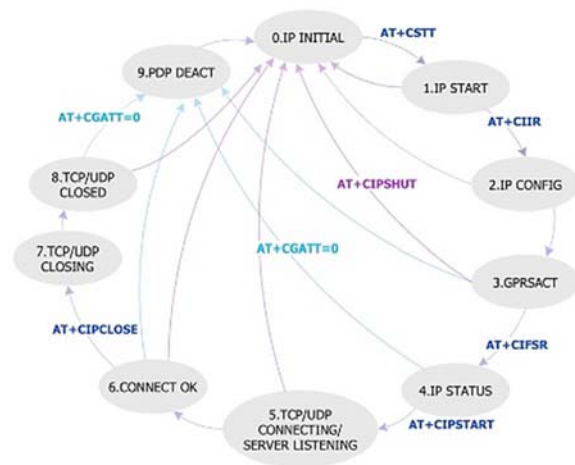


Fig. 13. GPRS State Diagram for single connection.

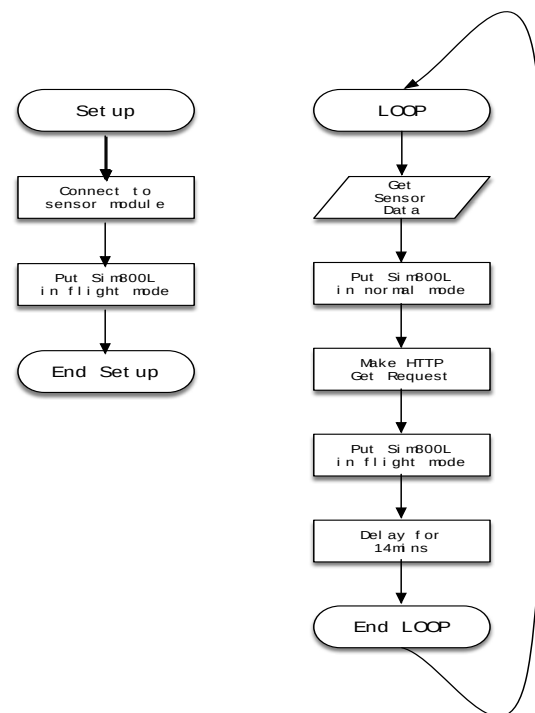


Fig. 14. Software communication program flow diagram.

3. The seawater monitoring station waits for data from the ocean environmental sensors module, which include DO, pH and temperature.
4. If data gathering is complete and the time interval for data transmission is reached, the seawater monitoring station will transmit the gathered data to the monitoring centre via GSM communication. Otherwise, go to Step 3.
5. The monitoring centre saves, processes and analyses the gathered data from knowledge sources, and displays the results, offering a subsequent decision-making tool.

The Sim800L module turns on as soon as it gets power. We developed an application to shut down the module when not transmitting data. After sending the sensed data to the remote monitoring centre the seawater monitoring station goes into standby, and the GSM module powers off and waits for the arrival of the next sampling point.

Next an HTTP request was made. The Simcom GSM modules has an HTTP request support built in, so, our application can make an HTTP GET request, to get the temperature, pH and DO every minute and shutting down the module in between.

To optimize the power consumption of the GSM module, we put it in flight mode when not in use, then put it back into normal. The Sim800L module turns on as soon as it gets power. We developed an application to shut down the module when not transmitting data. After sending the sensed data to the remote monitoring centre the seawater monitoring station goes into standby, and the GSM module powers off and waits for the arrival of the next sampling point.

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To optimize the power consumption of the GSM module, we put it in flight mode when not in use, then put it back into normal mode for data transmission.

5.2. The Design of the Central Monitoring Software Platform

The architecture of the system is a three-tier client/server model. Sensors of different physical quantities present the state of the situation transmitted via a GPRS network to the server, on which is analysed data from knowledge sources, offering a subsequent decision-making tool.

The operation of the remote monitoring platform is summarized according to the diagram presented in Fig. 15, in which the various parts of the system are presented. The system retrieves the values from the seawater monitoring station and stores them in a database.

Subsequently, the data-extraction process communicates the real-time monitoring data to the interface to generate real-time seawater parameter graphs based on the recorded data.

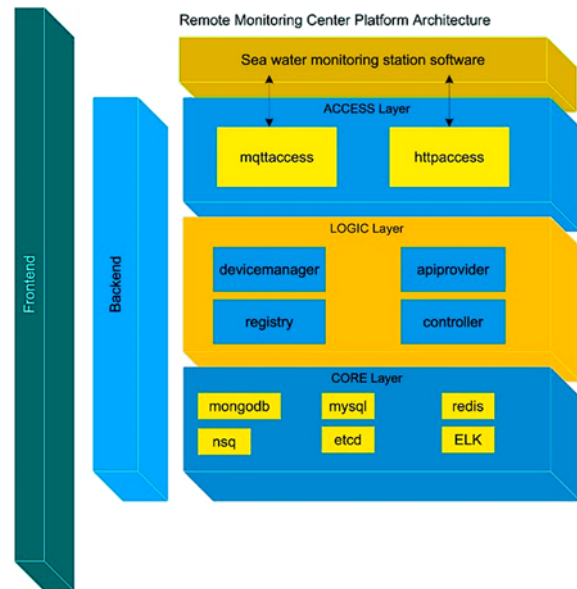


Fig. 15. Remote monitoring center software platform architecture.

Access layer.

The access layer provides a communication connection to devices using different protocols, including but not limited to the HTTP and the MQTT (Message Queue Telemetry Transport) protocol.

Device registration, authentication and device discovery use the HTTP protocol.

Business layer.

The logical business layer is used to implement the related services of the entire Internet of Things, such as device management and API (application programming interface).

Registry: responsible for maintaining platform-level configuration information and metadata.

Device manager: Device Manager is used to manage data requests for devices and processing devices and to maintain and monitor device status.

API provider: Provides the Restful API for application extensions and notifies the application server when the device status changes.

Controller: manages the device access service and routes the device request to the correct access service.

Core service layer.

Our core services choose the open source program: MongoDB: use mongodb as the device's data storage engine.

MySQL: Use MySQL to store the global configuration information for the same type of device.

Redis: Use redis to provide caching services.

Nsq: Asynchronous communication message queue as message notification centre.

Etd: Highly available key-value storage system, primarily for shared configuration and service discovery.

ELK: elk log analysis system that Logstash + Elasticsearch + Kibana4 combination refers to, mainly for logging and analysis.

This section describes how to complete the registration, login authentication and access data with the server when the device is connected to the network. The overall process is shown below

Data-transmission protocols.

The protocol needs to be implemented at the access layer and the hardware layer of both the seawater monitoring station and the remote monitoring centre.

The access layer is responsible for transmitting data back and forth between the GPRS module and the server. The hardware layer is responsible for transmitting data between the GPRS module and the MCU via the UART interfaces.

This section describes how to complete the registration, login authentication and access data with the server when the device is connected to the network. The overall process is shown in Fig. 16.

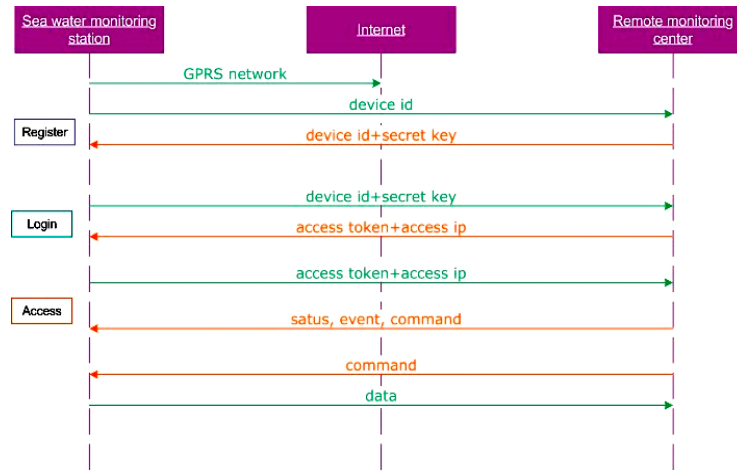


Fig. 16. Sequence Diagram of Data Transmission Protocols.

GPRS network:

Before starting all the processes, we must ensure that the device is connected to the Internet.

Registration:

View the local configuration at the seawater monitoring station, to see if the device ID and secret key configuration is present. If the device has been registered successfully, exit the registration process; otherwise continue.

The seawater monitoring station sends the device ID through the HTTP API to the server to register the device and waits for the server registration results.

The server verifies that the device ID is valid, and if the registration is successful, it returns a device ID and device secret. If the registration fails, try again until the device is registered successfully.

Login:

View the local configuration at the seawater monitoring station, and keep the device ID and device secret. If not, return to the registration process.

Verify the device ID and device secret to the server via the HTTP API. If successful, the server will return the device token and access address. If the server returns a failure, indicating that the device ID and device secret have expired, you need to delete the local device ID and device secret, and re-enter the registration process. If the server is not available or is timed out, retry until login is successful.

Access:

The details of the access procedure are related to the communication protocol, and the device is connected to the server (access address) with the specified communication protocol.

It must be reported to the access device token and device ID.

On the one hand, the service currently uses the device ID to distinguish which device it is attempting to access; on the other hand, the server will verify the device token and device ID, subsequent to verification by the information exchange.

Any data flow interaction with the server in the access process must verify the device token (including both the server and the device, which need to be checked against the token field in the protocol packet and should be discarded if not valid).

After the device is accessed, send the heartbeat packet to the server on a regular basis to keep the connection. Different types of devices have different heartbeat intervals.

In the case of token expiration, the server will close the connection or send a 'retry-login' command to the device. The gateway receives the re-entry process and obtains a new token.

When the device finds that the last heartbeat failed to send, re-enter the access process.

After the device completes the access process, the information is exchanged, including status, commands and events.

6. Conclusions

This remote-monitoring system makes up for a deficiency of traditional measuring and control systems. When used in actual research and application. Furthermore, to meet higher requirements, it cannot only be applied to aquaculture cages, but also to remote factory equipment and marine products transportation. Now as the automatic control level for mechanical-electrical integration increasingly improves, intelligent remote monitoring will become a major pillar of the information society.

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References

- [1]. Subasinghe, R. P., Epidemiological approach to aquatic animal health management: opportunities and challenges for developing countries to increase aquatic production through aquaculture, *Preventive Veterinary Medicine*, 67, 2005, pp. 117-124.
- [2]. Stigebrandt A., et al., Regulating the local environmental impact of intensive marine fish farming: III. A model for estimation of the holding capacity in the modelling-on growing fish farm-monitoring system, *Aquaculture*, 234, 2004, pp. 239-261.
- [3]. Sim F. S., Water quality index as a simple indicator of aquaculture effects on aquatic bodies, *Ecological Indicators*, 8, 2008, 476-484
- [4]. Heungwoo Nam et al., Remote Monitoring System based on Ocean Sensor Networks for Offshore Aquaculture, in *Proceedings of the Oceans-St. John's Conference*, 2014, pp. 14-19.
- [5]. Robert Herlien et al., An Ocean Observatory Sensor Network Application, *Sensors*, 2010, pp. 1837-1842.
- [6]. S. J. Park et al., Underwater Communications and under-water Sensor Network Technology, *Communications of the Korean Institute of Information Scientists and Engineers*, Vol. 29, No. 7, 2010, pp. 79-88.
- [7]. A. P. M. Michel, K. L. Croff, K. W. McLetchie and J. D. Irish, A remote monitoring system for Open Ocean Aquaculture, in *Proceedings of the OCEANS'02 MTS/IEEE Conference*, Vol. 4, October 2002, pp. 2488-2496.
- [8]. Xiaomei Xu and Xiaokang Zhang, A remote acoustic monitoring system for offshore aquaculture fish cage, in *Proceedings of the 14th International Conference on Mechatronics and Machine Vision in Practice (M2VIP'07)*, Dec. 2007, pp. 86-90.
- [9]. Xiaokang Zhang, Xiaomei Xu, Yangming Peng, Zheguang Zou, and Guanlong Su, Research on centralized remote monitoring system for offshore cage farm, in *Proceedings of the OCEANS'12 Conference*, Yeosu, May 2012, pp. 1-4.
- [10]. ATmega328 Datasheet, <https://www.farnell.com/datasheets/1693866.pdf>
- [11]. SIM800L Datasheet, <http://www.datasheetcafe.com/sim800l-datasheet-simcom/>
- [12]. DS18B20 Waterproof thermometer, <https://www.sparkfun.com/products/11050>



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