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A Ship Exhaust Gas Monitoring Equipment based on NBIoT

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Abstract

Because of the severe problem of ship exhaust pollutant emission and the high cost, high power consumption of relevant ship exhaust monitoring schemes in the market, a ship exhaust monitoring equipment based on NBIoT (Narrow Band Internet of Things) is designed in this study. This equipment includes four parts: the power management unit, the minimum system unit, the communication circuit unit and the ship exhaust gas monitoring circuit unit. The overall process of the equipment is that the power management unit supplies power for the whole system; the minimum system unit starts the processing program and NBIoT communication program of ship exhaust gas monitoring; after receiving the power supply, the minimum system unit uploads the ship exhaust gas parameters measured by the ship exhaust gas monitoring circuit unit to the CVM(Cloud Virtual Machine) through the communication circuit unit. In this study, the ship exhaust monitoring equipment is installed at a fixed point in Gezhouba, and the coordinate position of the equipment is manually input to the cloud to conduct real-time monitoring of the exhaust emission of vessels passing through the lock. The results show that the equipment integrates ultra-low power consumption and low cost, is easy to set up, and can operate stably. It realizes real-time monitoring of SO2, CO2, NO2, and NO pollutants from ship exhaust.

Keywords

NBIoT; Ship Exhaust; CVM; Ultra-low Power Consumption.

1. Introduction

In recent years, with the economic development and policy support of China, the shipping industry has been vigorously developed. The volume of goods transported by water in China grew from 6.136 billion tons in 2015 to 8.240 billion tons in 2021 [1,11]. China holds eight of the world's top ten ports and Seven of the world's top ten container ports [2,3]; the port cargo throughput in China completed 15.545 billion tons in 2021, firmly ranking first in the world. At the same time, China is a country with rich inland shipping resources [10]. The Statistical Bulletin of Transport Industry Development in 2021 shown that by the end of 2021, the number of inland waterway transport vessels nationwide was 113,600; the net deadweight reached 146,769,200 tons; inland river ports completed the cargo throughput of 5.573 billion tons, an increase of 21.07% compared with 2015; the turnover of inland river cargo was 1,773.599 billion ton-kilometers, an increase of 33.23% compared with 2015. The navigable mileage of inland waterways in China is 127,600 kilometers, ranking first in the world; The freight volume of the Yangtze River trunk line reached 3.530 billion tons, ranking first in inland waterway shipping for more than 10 consecutive years. Along with the prosperous development of water transportation, the pressure and challenges brought by ship air pollution emissions to regional air quality should not be underestimated. During sailing and berthing, vessels continuously emit air pollutants such as sulfur oxides, nitrogen oxides, and VOCs (Volatile Organic Compounds). According to statistics, pollution caused by ship exhaust gas accounts for about 10% of the whole air pollution [12-14]. When these pollutants migrate inland with the

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atmosphere, they may aggravate the air pollution in cities, causing harm to human health and the ecological environment [15-17]. In 2013, sulfur dioxide emissions from ships accounted for about 8.4% of the total national emissions and 11.3% of nitrogen oxide emissions [5]. 50% of ship pollution was caused by waterway transportation.

The exhaust gas pollution produced by ships during navigation has become the primary source of air pollution in dense shipping waters [4]. Facing the severe impact of ship exhaust on the ecological environment, the International Maritime Organization (IMO) has formulated and issued various regulations to prevent ship pollution [18]. In 2018, the Ministry of Transport of China issued the Implementation Plan for Ship Air Pollutant Emission Control Zones (hereinafter referred to as the Plan) in 2018 to control ship pollution in the emission control zones. According to the Plan, sea-going vessels entering the emission control area shall use Marine fuel with sulfur content less than 0.5%m/m from January 1, 2019, and sea-going ships entering the inland river control area shall use Marine fuel with sulfur content less than 0.1%m/m from January 1, 2020 [18]. Ships built in different years should meet the NOx emission requirements of MARPOL (International Convention for the Prevention of Pollution from Ships) at different stages (Table 1). Therefore, it becomes critical to strengthen the ship exhaust monitoring.

Table 1. Nitrogen oxide emission control requirements

Date of construction (conversion)	Type of vessel	Emission requirements
Jan.1, 2000 and later	International ship	Tier Ⅰ
Jan.1, 2011 and later	International ship	Tier Ⅱ
Jan.1, 2015 and later	Domestic navigation ships of Chinese nationality	Tier Ⅱ
Jan.1, 2022 and later	Domestic navigation ships of Chinese nationality	Tier Ⅲ

Aiming at the vital work of ship exhaust monitoring, Wang Jiayao et al. [19] carried out ship exhaust emission monitoring by UAV (Unmanned Aerial Vehicle) equipped with the gas monitoring equipment, and adopted Bluetooth communication module design to achieve successful connection between mobile terminal and exhaust detection equipment, and finally presented ship exhaust monitoring data information on Android application interface. Shi Huajie et al. [20], and Xu Shunji et al. [21] carried out the monitoring work of ship exhaust emissions through UAVs, using GPRS (General Packet Radio Service) data flow as a data transmission channel and uploading the emission results to SVM as a way to complete the monitoring task. Wu Jianhua et al. [12] proposed a telemetry data analysis system for ship exhaust gas based on WebGIS (Network Geographic Information System), adopting the 4G (the 4th generation mobile communication technology) network of telecommunication, WebGIS and IoT (Internet of Things) to realize the remote monitoring method for ship exhaust. Ji Qingpeng et al. [22] used LoRa (Long Range Radio) data transmission technology to conveniently and quickly realize the rapid telemetry of gaseous pollutant emission from ships in the area with no telecommunication operation. These monitoring schemes have been relatively mature, but the shortcomings are obvious: Bluetooth communication technology is suitable for short-range communication, and can not achieve remote monitoring; High power consumption of the GPRS module and 4G module results in short standby time of the equipment; LoRa module needs to build a base station with high investment cost. As one of the key access technologies for IoT [6], NBIoT is one of the LPWAN (Low-Power Wide-Area Network) wireless communication networks. LPWAN is a wireless network used in the IoT (such as battery-powered sensors) to

ISSN: 2710-0588

communicate over long distances at low bit rates. Low power demand, low bit rates, and timing of use are the key factors that distinguish LPWAN from wireless wide-area networks, which are designed to connect businesses or users and can transmit more data but consume more energy. With the implementation of the LPWAN wireless communication network [9], there are many prospects in the field of ship exhaust gas monitoring. NBIoT is capable of handling large numbers of connections with low power consumption, extending battery life, and providing 20dB extended coverage (especially indoor deep penetration) compared to GPRS. Most prominently, it provides reliable services by using licensed frequency bands and avoids congestion problems [8].

Accordingly, considering the problems existing in the current ship exhaust monitoring schemes, combined with the characteristics of low cost and low power consumption of NBIoT, this study proposes a ship exhaust monitoring equipment based on NBIoT. The equipment can be installed at a fixed point to carry out real-time monitoring of the exhaust gas of sailing ships, greatly improving the breadth of monitoring, realizing the convenience of equipment installation, ultra-low power consumption, and reducing the cost of monitoring.

2. Ship Exhaust Gas Monitoring Equipment based on NBIoT

The ship exhaust gas monitoring equipment designed in this research is used to monitor the exhaust gas of sailing ships. The equipment is applied to the real-time monitoring of the exhaust gas of inland ships by fixed point installation. The equipment provides real-time monitoring of SO2, CO2, NO2, and NO concentrations in exhaust gas, and combines technologies such as Vue front-end framework, Java back-end language, and access to MySQL data through MyBatis framework to realize a ship exhaust gas monitoring system with comprehensive and complete functions, good real-time performance, and robust data management and analysis capabilities.

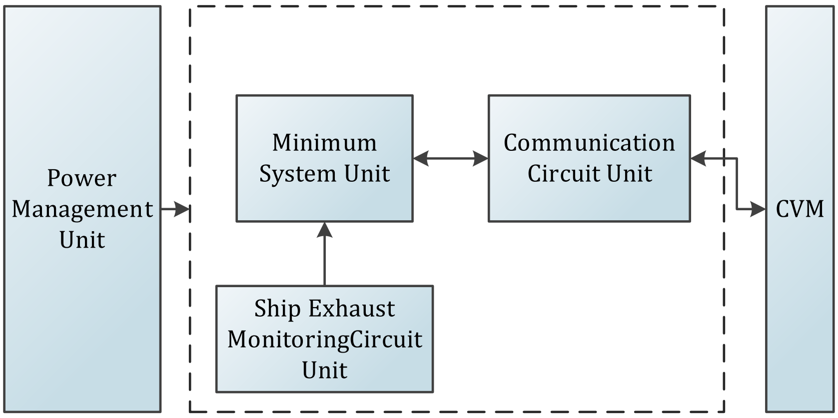

Figure 1. System unit structure diagram

The system structure of the ship exhaust gas monitoring equipment based on NBIoT is shown in Figure 1, which mainly includes the power management unit, the minimum system unit, the communication circuit unit and the ship exhaust gas monitoring circuit unit. Where the power management unit is connected to the other three units respectively, and is responsible for the power supply protection and management of the whole equipment; The minimum system unit is connected with the communication circuit unit and the ship exhaust gas monitoring circuit unit respectively, which is used for the storage and operation of the microprocessor system code; The communication circuit unit communicates with the CVM directly, which is used for information exchange between the minimum system unit and the CVM, uploads the monitoring data and alarm information of the ship exhaust gas; The ship exhaust gas monitoring circuit

ISSN: 2710-0588

unit is used to detect SO2, CO2, NO2, NO and other key parameters of ship exhaust gas, and upload the ship exhaust gas parameters to the minimum system unit for processing.

During the operation of the equipment, the power management unit supplies power to the whole system, and the system starts the ship exhaust gas detection and processing program and NBIoT communication program after the minimum system unit gets the power supply. When switched on, the ship exhaust gas monitoring unit monitors the concentration of SO2, CO2, NO2 and NO in the environment in real time, as well as meteorological conditions such as wind speed, temperature and humidity. When the underway ships pass by, the concentrations of gases SO2, CO2, NO2 and NO monitored by the ship exhaust monitoring unit in real time will change, and the minimum system unit will process these exhaust parameters and later upload them to the SVM in real time through the communication circuit.

2.1. Power Management Unit

As shown in Figure 2, the power management unit is composed of six parts: the charging management module, a battery, the short-circuit protection, the anti-reverse connection protection, the overvoltage protection and the electricity meter module, which is mainly used to power the whole system. External interface to connect the charger charging, charging management module will be charging port input voltage is converted into an acceptable battery charging voltage. In order to protect the ship exhaust gas monitoring equipment; when the abnormal load current is too large, short circuit protection module cuts off the power supply; when the battery reverse connect, anti-reverse connection protection module cuts off the power supply. The electricity meter module monitors the remaining battery power in real time, when the battery power is too low, an alarm is reported to the cloud server.

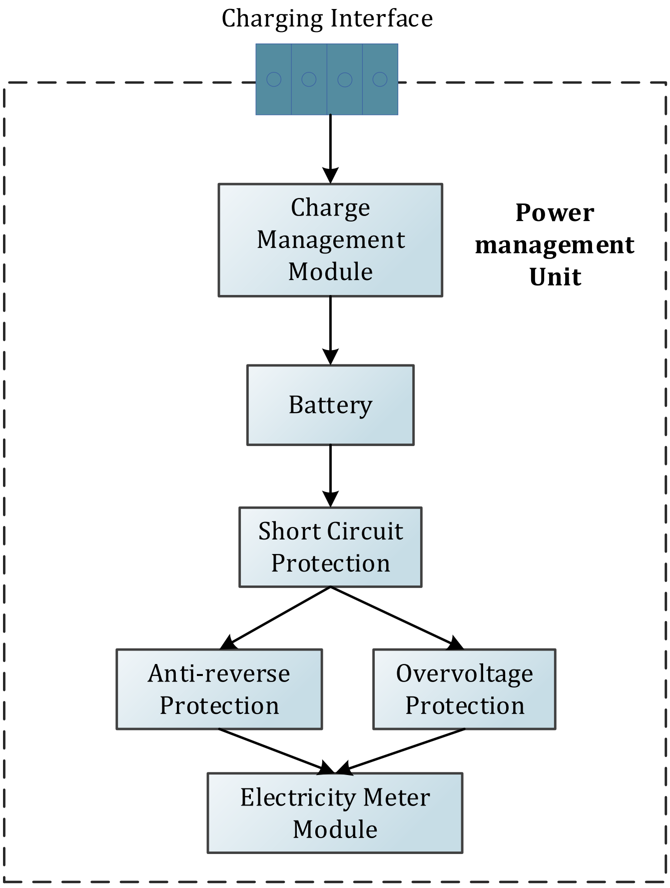

Figure 2. Power Management Unit

ISSN: 2710-0588

Figure 3 shows the specific circuit module structure of the power management unit. It is known that the power management unit is composed of six parts. Next, we will fully elaborate the details of each part.

(1) Charging management module. The module includes two capacitors (C4 and C5) and a battery charge management chip. C4 and C5 are components of multiple capacitors in parallel, which buffer and filter the input voltage and output voltage of the power supply respectively. The battery charge management chip converts the input voltage into the battery charge voltage. C4, battery charge management chip, and C5 are directly connected in terms of electrical properties.

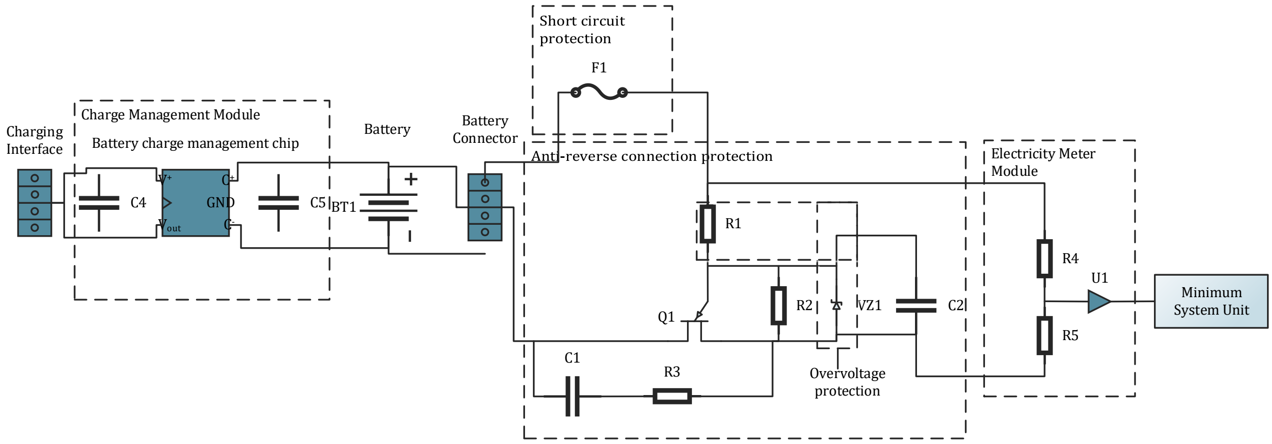

Figure 3. the specific circuit module structure of the power management unit

(2) Short-circuit protection module. This module is mainly composed of F1 (fuse), which can cut off the power supply to protect the ship exhaust monitoring equipment when the load current is abnormally large.

(3) Anti-reverse connection protection and overvoltage protection module. This module consists of Q1 (MOS tube), VZ1 (voltage regulator), three resistors (R1, R2, R3), and two capacitors (C1 and C2). Q1, R1, R2, R3, C1 constitute anti-reverse connection protection module; VZ1 and R1 form the overvoltage protection module, which is used to protect the ship exhaust monitoring equipment as a whole.

(4) Electricity meter module. This module includes two resistors (R4 and R5) and a buffer U1. R4 and R5 are composed of multiple resistors in series and parallel connection to form a voltage division network. The voltage division network is used to attenuate the battery voltage and prevent the microprocessor of the minimum system unit from being damaged due to the excessively high battery voltage entering the detection end of the minimum system unit. U1 is used to suppress the voltage signal overshoot generated by battery insertion and removal to protect the safe and reliable operation of the minimum system unit.

(5) Battery module. This module consists of a battery and a battery port. The battery of the module is used to store the electrical energy for the standby and working of the ship exhaust monitoring equipment.

2.2. Minimum System Unit

The minimum system unit consists of four parts: microprocessor, clock circuit module, reset circuit module and program online debugging and downloading module, as shown in Figure 4, which is used for the storage and operation of the microprocessor system code. The microprocessor adopts the low-power architecture, supports the operation of lightweight operating system, supports the function of self-monitoring, and is directly connected with the clock circuit module, reset circuit module, and program online debugging and downloading

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module in the electrical properties. After the minimum system unit is powered by the power management unit, the clock circuit module starts first, then the reset circuit module starts, and last the microprocessor starts. After the microprocessor starts, it reads the system code and data from the memory and starts the ship exhaust monitoring program and communication program.

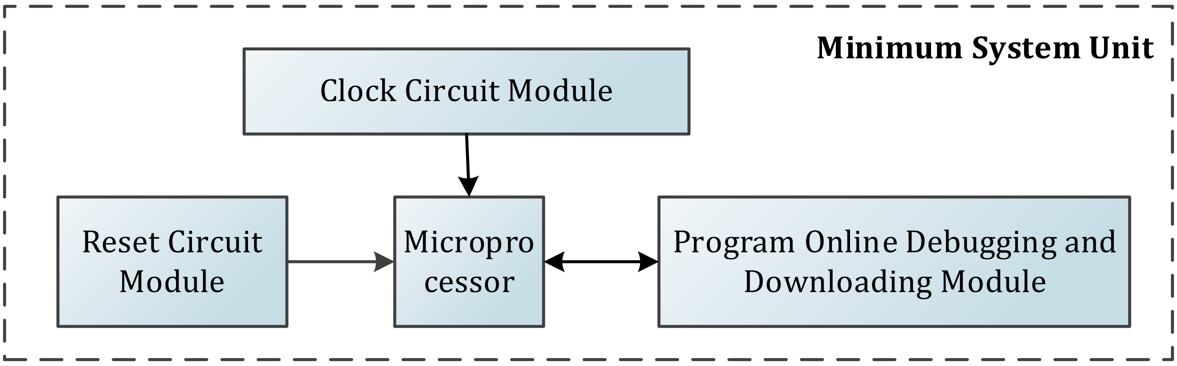

Figure 4. Minimum System Unit

2.3. Communication Circuit Unit

As shown in Figure 5, the communication circuit unit mainly includes the NBIoT module, the eSIM card module and the antenna. Regarding electrical attributes, the NBIoT module is directly connected with the microprocessor included in the minimum system unit and the eSIM card module is directly connected to the NBIoT module. The eSIM card module is used to store the tariff information of the carrier. This module is used to realize the information interaction between the minimum system unit and the CVM.

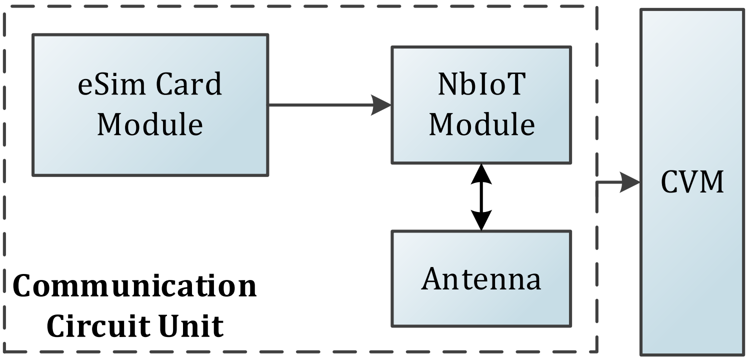

Figure 5. Communication Circuit Unit

2.4. Ship Exhaust Gas Monitoring Circuit Unit

The ship exhaust gas monitoring circuit unit includes SO2 sensor module, CO2 sensor module, NO2 sensor module, NO sensor module, coefficient compensation sensor module, and micro signal processing module. As shown in Figure 6, four gas sensor modules and the coefficient compensation sensor module are directly connected to the micro signal processing module on electrical properties, and the micro signal processing module uploads the preliminary processed data to the microprocessor of the minimum system unit. The micro signal processing module is directly connected to the microprocessor of the minimum system unit on electrical properties. This module is used to directly measure the ship exhaust gas parameters and upload the ship exhaust gas parameters to the minimum system unit for processing.

ISSN: 2710-0588

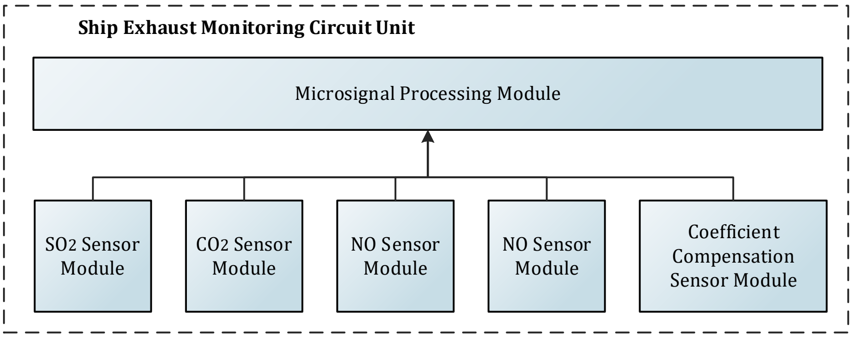

Figure 6. Ship Exhaust Gas Monitoring Circuit Unit

Figure 7 shows the specific circuit module structure of the NBIoT-based ship exhaust monitoring equipment.

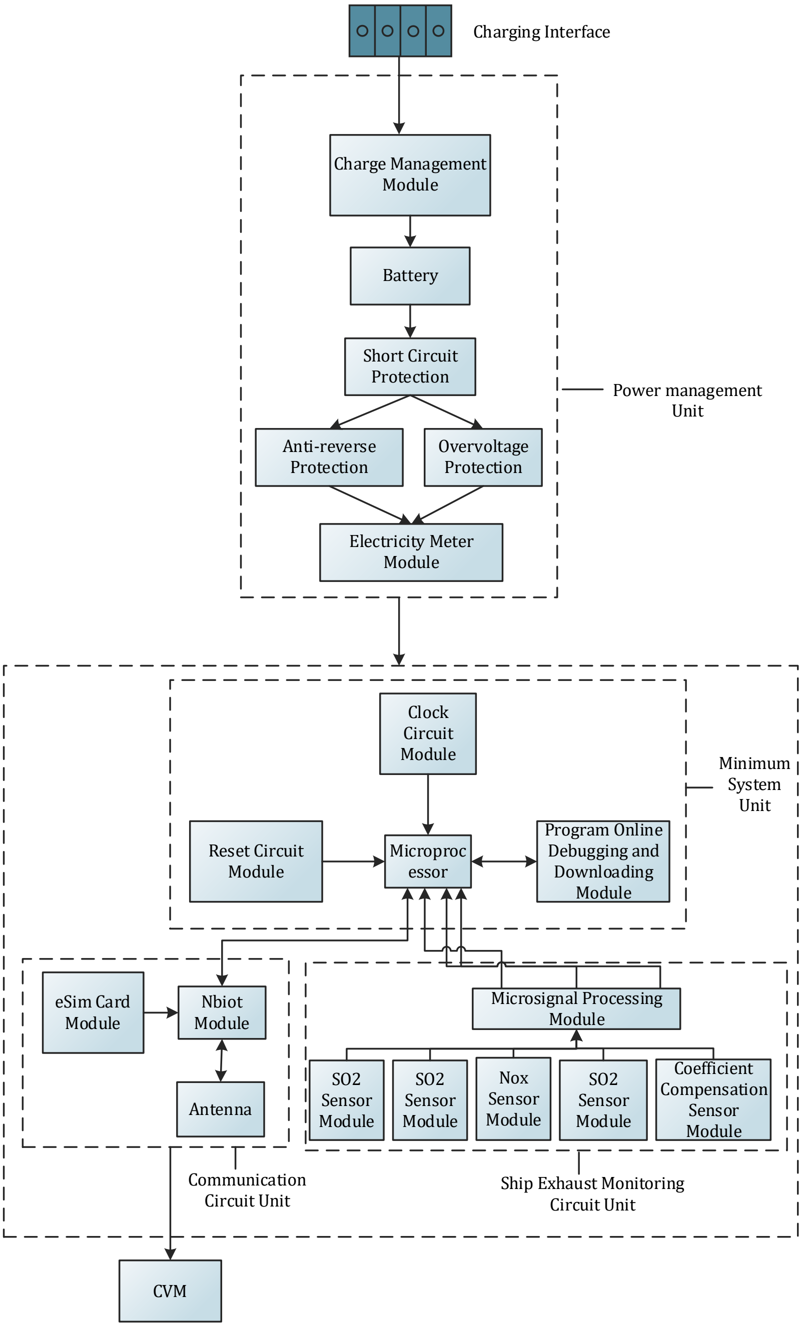

Figure 7. Ship exhaust gas monitoring circuit unit

ISSN: 2710-0588

3. The Experimental Test

The test site of this experiment was selected in Gezhouba, Yichang City, Hubei Province, and the equipment was fixed above the No.3 lock. The test held for eight days from April 1, 2021 to April 8, 2021. Experimental conditions: the wind speed was less than level 3, and the temperature variation ranged from 10.8°C to 19.4°C. Although the concentrations of the constituents of different ship exhausts are different, the proportion of the gases diluted by diffusion with the wind is the same, so the difference concentration in the wind diffusion process can be neglected. When no ship is passing, the equipment has been monitoring the gas concentration of the surrounding environment, also known as the background concentration, and the gas concentration monitored by the equipment fluctuates as the ship passes through the gate, and returns to the background value as the ship leaves. When there is no ship passing by, the equipment continuously monitors the gas concentration of the surrounding environment, which known as the background concentration. When the ship passes through the lock, the gas concentration monitored by the equipment fluctuates, and returns to the background value as the ship leaves.

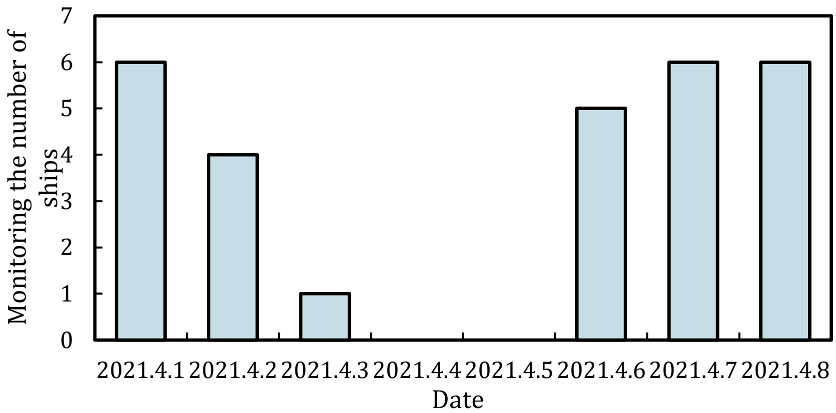

Figure 8. Number of ships under monitoring

The situation monitored by the equipment is shown in Figure 8. A total of 28 vessels were monitored within eight days. The equipment can accurately monitor the concentration of CO2, SO2, NO2 and NO in the exhaust gas of each ship, realizing real-time monitoring, and uploading the data to the server once per second or every second.

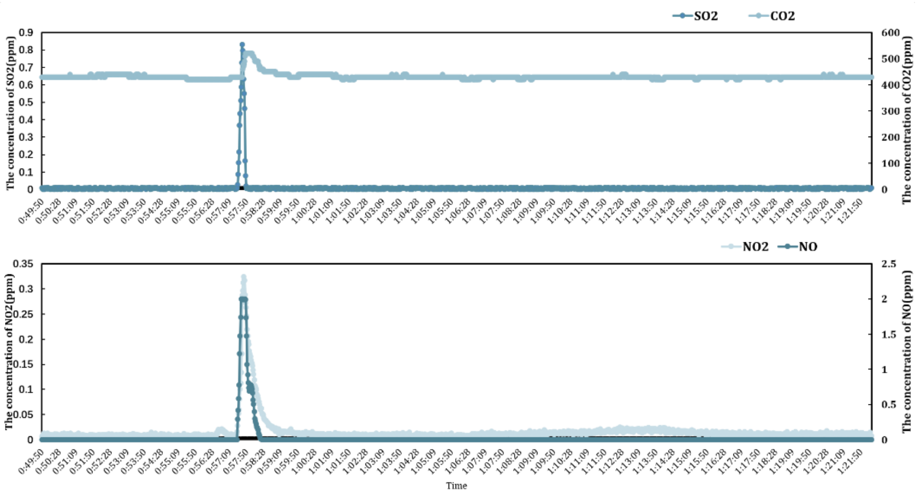

Figure 9. Ship exhaust monitoring results

ISSN: 2710-0588

Figure 9 shows the concentration results of exhaust gas of one of the ships monitored by the equipment. The monitoring curve shows the real-time changes of the concentration of SO2, CO2, NO2 and NO in the exhaust gas in air. The upper part is the concentration curves of SO2 and CO2. The light color curve is CO2 concentration, and the dark color curve is SO2 concentration; The lower part shows the concentration curves of NO and NO2. The light color is NO2, and the dark color is NO.

As can be seen from the figure, the concentrations of SO2, CO2, NO2 and NO all increased first and then decreased, that is, when the ship approached the equipment, the gas concentration in the tail gas of the ship increased. This experiment verifies the reliability of the NBIoT-based ship exhaust monitoring equipment, which can lay a foundation for the subsequent calculation of fuel sulfur content, emission factors and emissions.

4. Conclusion

In this study, NBIoT communication technology was used to design the ship exhaust gas equipment. Through continuous research and analysis, the equipment was installed on Gezhouba lock at fixed points for experiment and application. Through the eight-day monitoring task, the concentration of SO2, CO2, NO2 and NO gas in the exhaust gas of 28 ships was detected. This study fully combines Vue front-end framework, Java back-end language, MySQL data access based on MyBatis framework and other technologies to realize real-time monitoring data visualization, and fully verifies the reliability, integrity and practicability of NBIoT-based Ship exhaust gas monitoring equipment.

On the one hand, this study provides a monitoring equipment for the emission of Ship exhaust pollutants, and on the other hand, it solves the problems of monitoring schemes in the market, such as high power consumption of the GPRS module and 4G module, short standby time of equipment, high input cost of ZIGBEE(ZigBee Technology) module and LoRa module. Through NBIoT access technology, the ship exhaust gas monitoring equipment was installed at fixed points during the experiment and was able to accurately detect the concentration of ship exhaust gas pollutants in real time. The operation effect is good, and the equipment installation is convenient, ultra-low power consumption and low cost. However, this study still needs to be carried out further: based on the ship exhaust concentration monitored by this equipment, it can be used for the subsequent calculation of fuel oil sulfur content, providing technical support for maritime enforcement officers to screen the fuel oil sulfur content exceedance; providing data support for the calculation of local emission factors and emissions.

This equipment, together with the UAV monitoring technology and the emission monitoring technology of on-board ships, will improve the supervision on maritime issues, provide robust data support for the prevention and control of air pollution of Chinese ships, and contribute to the realization of green and low-carbon shipping, helping to achieve "carbon peak" and "carbon neutrality".

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