Journal of Computer Science and Electrical Engineering
ISSN: 2663-1938
DOI: 10.61784/jcsee3019

DESIGN OF A CAT3512B DIESEL GENERATOR DATA ACQUISITION SYSTEM BASED ON STM32

YuanJu Zhou
Chengdu Jiushang Technology Co., Ltd., Chengdu 610000, Sichuan, China.
Corresponding Email: yjzhou.2008@163.com

Abstract: The CAT3512B generator set, renowned for its efficient and stable operation as well as robust power support, has found widespread application across various industries such as engineering machinery, petroleum, power industry, and chemicals. This article presents a data acquisition system designed utilizing embedded technology and IoT applications, centered on the STM32F103C8T6 microcontroller. This system is tasked with real-time acquisition, transmission, and application of operational parameters from both the engine and generator of the CAT3512B generator set. The objective is to facilitate real-time monitoring and early warning, enabling historical data retrieval of operational parameters. Leveraging big data and AI algorithms, it further aids in preventive and precise maintenance, providing management with data-driven, scientifically sound decision support.The data acquisition unit employs the STM32F103C8T6 chip, which strikes an excellent balance between performance and cost. Engine parameters are collected via the CAN bus, while electrical parameters from the generator are gathered using an Rs485 bus interface with an electrical parameter tester. The acquired data is packaged into the corresponding message format of the data platform and transmitted to the data processing center via the NB-IoT communication module for analysis, storage, and application.
Keywords: STM32F103C8T6; CAT3512B; CAN bus; Rs485 bus; NB-IoT

1 INTRODUCTION

The significance of real-time monitoring of equipment operational parameters and early warning information cannot be overstated in modern industrial production and maintenance. It plays a pivotal role in effectively preventing equipment failures, enhancing efficiency and energy consumption ratios, ensuring production safety, leveraging big data and AI algorithms for preventive and precise maintenance, facilitating data visualization and historical trend analysis, and ultimately providing data-driven, scientifically sound decision support for management.

The CAT3512B generator set, renowned for its efficient and stable operation coupled with robust power output, has found widespread application across industries such as engineering machinery, petroleum, power, and chemicals. Its exceptional performance and versatility have made it a highly sought-after product in the market, providing vital energy support for various industries' production and development.

To effectively utilize these generators' operational parameters for monitoring, diagnosis, maintenance, and control, real-time data acquisition and warning information, along with a seamless communication channel between the equipment and the data center, are crucial. This article designs a data acquisition system for CAT 3512B diesel generator sets based on the STM32F103C8T6 microcontroller, which collects engine and electrical parameters to provide data support for real-time monitoring of equipment operation and subsequent data analysis applications.

2 DESIGN PLAN

2.1 Overall Hardware Design Plan

The STM32F103C8T6 is a high-performance, low-power 32-bit microcontroller introduced by STMicroelectronics. Based on the ARM Cortex-M3 core, it features high performance and low power consumption. With a 32-bit bus width and a maximum clock frequency of 72MHz, it provides fast data processing capabilities. It has 64KB of Flash memory for storing program code and 20KB of SRAM for storing runtime data. The operating temperature ranges from -40°C to 85°C, ensuring stable operation in various industrial environments. This chip integrates a variety of on-chip peripherals, including USART, CAN, USB, and ADC, to facilitate data exchange with other peripherals or devices.

The STM32F103C8T6 is widely used in various embedded control and computing fields, including but not limited to: industrial control, automotive electronics[1], smart home, Smart Agriculture [2],and medical equipment.

This article designs a data collector for monitoring real-time parameters during the operation of the CAT3512B generator. Based on the working principle of the CAT3512B generator, the data can be divided into engine operating parameters and generator operating parameters. The data collector adopts an embedded design and is equipped with an Rs485 transceiver (Max3485) and a CAN transceiver (TJA1050). The main functions of the collector include: collection of engine operating parameters and alarm data, collection of generator operating parameters, and data transmission module. The specific design plan is shown in Figure 1:

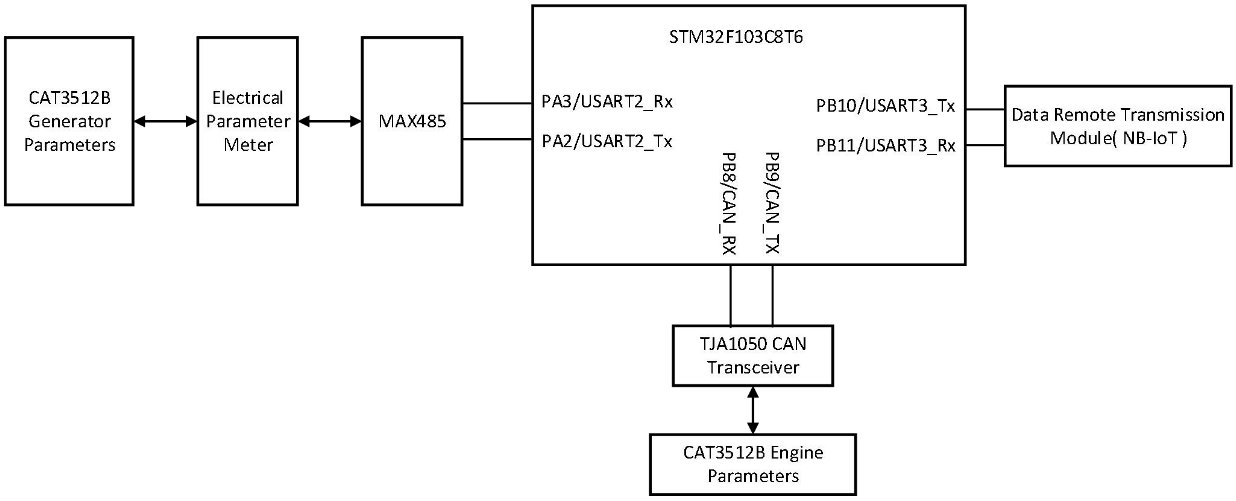

Figure 1 Hardware Design Plan

The engine data primarily encompasses engine load, fuel pressure, oil pressure, fuel level, coolant temperature, and alarm parameters during engine operation. This data is transmitted using the J1939 protocol[3][4], with the parameter message structure conforming to the CAN 2.0B protocol. The STM32F103C8T6 microcontroller, leveraging its on-chip peripherals, accomplishes real-time data acquisition and processing of the engine through the TJA1050 CAN transceiver.

Generator parameters include three-phase voltage, three-phase current, power factor, active power, reactive power, among others. These generator parameters are collected by an electrical parameter meter, and the acquisition unit retrieves these parameters from the meter via an RS485 communication port, utilizing the Modbus-RTU communication protocol.

The data remote transmission module mainly uses the NB-IoT communication module to report the real-time collected engine and generator data to the data center.

2.2 Overall Software Design Plan

The data collector uses a table lookup method for data caching, which effectively improves the execution efficiency of the microcontroller, reduces the consumption of computational resources, facilitates post-upgrade maintenance and expansion of the software, and to some extent, simplifies multi-business interaction. In terms of business design, a combination of interrupts and timer polling is employed. Engine data is received via CAN interrupts, and after comparing with the PGN through table lookup, it is cached as shown in the table; generator data is periodically polled from the electrical parameter instrument using the Modbus protocol, verified, and then stored in the generator parameter table; the data transmission module regularly queries the parameter table and reports data according to the protocol. The software process is illustrated in Figure 2:

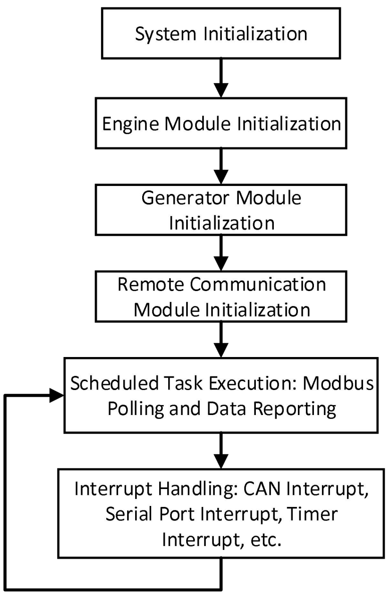

Figure 2 Software Design Process

3 ENGINE MODULE

3.1 Engine Parameter

The CAT 3512B engine, during its operation, transmits message parameters that adhere to the SAE-J1939 protocol. SAE-J1939 is a recommended standard established by the Society of Automotive Engineers (SAE) specifically designed for digital communication among electronic components in medium- and heavy-duty on-road vehicles as well as off-road vehicles (including construction machinery, agricultural machinery, rail vehicles, ships, etc.). Built upon the Controller Area Network (CAN) technology developed by Bosch in Germany, SAE-J1939 serves as the High-Level Protocol (HLP) for CAN, providing a standardized architecture to enable communication between electronic control units (ECUs) from different manufacturers. The parameters of the CAT 3512B engine during operation are listed in Table 1, with the following common parameter:

3.1.1 Engine Status Parameters

RPM (Revolutions Per Minute): Indicates the current rotational speed of the engine, crucial for monitoring engine performance.

Fuel Consumption Rate: Measures the amount of fuel consumed by the engine per unit time, essential for assessing engine efficiency and fuel management.

Coolant Temperature: Reflects the status of the engine's cooling system, vital for preventing engine overheating.

Oil Pressure and Temperature: Key parameters ensuring the proper functioning of the engine's lubrication system.

3.1.2 Performance Parameters

Torque Output: Indicates the amount of torque produced by the engine under current operating conditions, significant for evaluating engine power performance.

Power Output: The actual power output of the engine, typically measured in kilowatts (kW) or horsepower (hp).

Fuel Efficiency: Represents the engine's ability to convert fuel into mechanical energy, impacting both economy and environmental friendliness.

3.1.3 Fault Diagnosis and Warning Parameters

Fault Codes: Generated when the engine or related systems encounter faults, transmitted via the CAN bus to the monitoring system for diagnosis.

Sensor Status: Includes readings and status information from various sensors (e.g., temperature sensors, pressure sensors, speed sensors) to monitor engine operation.

Warning Information: Alerts operators or maintenance personnel when the engine or related systems are approaching critical conditions.

3.1.4 Control Parameters

Fuel Injection Control: Involves parameters such as fuel injection quantity and timing, crucial for precise control of the engine's combustion process.

Intake Control: Encompasses parameters like turbocharger control and intake air volume adjustment, optimizing the engine's intake efficiency.

Emission Control: Includes parameters for Exhaust Gas Recirculation (EGR) control, aftertreatment system control, and others, ensuring compliance with emission regulations.

Table 1 Engine Partial Parameter Information Table

PGN (Parameter Group Number)	Parameter Name	Data Range
0xF003	Engine Percent Load At Current Speed	0 to 250 %
0xF004	Engine Speed	0 to 8,031.875 rpm
0xFEDF	Engine's Desired Operating Speed	0 to 8,031.875 rpm
0xFEE5	Engine Total Hours of Operation	0 to 210,554,060.75 hr
0xFEE9	Engine Total Fuel Used	0 to 2,105,540,607.5 L
0xFEEE	Engine Coolant Temperature	-40 to 210 deg C
0xFEEF	Engine Oil Pressure	0 to 1000 kPa
0xFEF2	Engine Fuel Rate	0 to 3,212.75 L/h
0xFEF5	Barometric Pressure	0 to 125 kPa
0xFEF6	Engine Turbocharger Boost Pressure	0 to 500 kPa
0xFEF7	Battery Potential (Voltage), Switched	0 to 3212.75 V
0xFE06	Engine Exhaust GAS Temperature-Right Manifold	-273 to 1735 deg C
0xFE92	Unfiltered Engine Oil Pressure	0 to 1000KPa

3.2 Analysis of Engine Alarm Information

SAE J1939, at the application layer, defines various diagnostic messages (DM) and diagnostic trouble codes (DTC) for fault diagnosis and monitoring. Here are the common diagnostic information types within SAE J1939:

(1)Diagnostic Message 1 (DM1) – Active Diagnostic Trouble Codes: This message is used to transmit currently active fault codes that indicate issues with the vehicle's systems. Users typically utilize DM1 to read these active fault codes. DM1 corresponds to a Parameter Group Number (PGN) of 65226 or hexadecimal FECA.
(2)Diagnostic Message 2 (DM2) – Inactive/Historically Active Fault Codes: This message type carries fault codes that were once active but are no longer current, providing a historical record of faults.
(3)Diagnostic Message 3 (DM3) – Clear Inactive Fault Codes: This message is used to request the clearing of inactive fault codes from the system's memory.
The diagnostic trouble codes (DTCs) themselves are structured into three main components, Each DTC is composed of 4 bytes, with the bit allocation for the three components typically structured shown in Table 2:
(1)Suspect Parameter Number (SPN): This identifies the specific parameter or system associated with the fault.
(2)Failure Mode Identifier (FMI): This indicates the specific type of failure or issue related to the parameter identified by the SPN.
(3)Occurrence Count (OC): This counts the number of times the fault has occurred or been detected.

Table 2 DTC Representation in CAN Data Frame for DM1 (Byte 3 Closer to CAN Identifier)

<table>
<tr><td colspan="32">DTC</td></tr>
<tr><td colspan="8">Byte3
8 least significant bits of SPN
(bit 8 most significant)</td><td colspan="8">Byte4
send byte of SPN
(bit 8 most significant)</td><td colspan="8">Byte5
3 most significant bits of SPN
and the FMI
(bit 8 SPN msb and bit 5 FMI
msb)</td><td colspan="8">Byte6</td></tr>
<tr><td colspan="19">SPN</td><td colspan="5">FMI</td><td>C
M</td><td colspan="7">OC</td></tr>
<tr><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td></tr>
</table>

3.3 Hardware Design for Engine Parameter Acquisition

In this article, the bxCAN (Basic Extended CAN) controller of the STM32F103C8T6 is utilized to establish a connection with the CAN bus of the CAT3512B engine. The CAN transceiver TJA1050 converts the signals from the CAN controller into corresponding differential signals for the CAN bus, enabling communication with other CAN devices. The key features of the bxCAN controller include:
(1)Compatibility with CAN Protocols: The bxCAN supports both CAN protocol 2.0A and 2.0B in active mode, allowing it to be compatible with different versions of the CAN standard.
(2)Multi-level Depth FIFO: It features two receive FIFOs, each with a depth of three levels. This enables the storage of multiple complete messages, which are automatically managed by hardware, thereby reducing the burden on the CPU.
Variable Filter Banks: It provides 14 filter banks (Standard CAN) or 28 filter banks (Extended CAN) with variable bit widths. This allows the software to configure the filter banks to select only the required messages while discarding others, enhancing communication efficiency.
(3)Receive Timestamp: It records the timestamp of the Start of Frame (SOF) moment, facilitating synchronization and analysis of the received data.
The TJA1050, as a high-performance CAN bus transceiver, is widely used in IoT (Internet of Things), industrial electronics, and automotive electronics applications. Its key attributes include:
(1)Wide Temperature Range: The TJA1050 supports a broad temperature range, making it suitable for industrial control and automotive applications.
(2)Strong EMI Resistance: Designed to minimize surge interference caused by electromagnetic radiation, it possesses robust electromagnetic interference (EMI) resistance, capable of withstanding electromagnetic noise from the external environment, including surges that may be induced.
(3)Protection Against Surge Damage: The TJA1050 integrates protection components such as transient voltage suppression (TVS) diodes, effectively safeguarding the chip from surge damage.
This combination of the STM32F103C8T6's bxCAN controller and the TJA1050 CAN transceiver enables reliable and efficient communication with the CAT3512B engine's CAN bus.

3.4 Software Design for Engine Parameter Acquisition

Engine parameter tables are divided into Engine Parameter Group Number (PGN) parameter tables and alarm information parameter tables. The PGN parameter table primarily includes parameters such as PNG, parameter location, parameter length, resolution, etc. It is used for looking up and comparing parameters, as well as caching parameters reported by the engine. The alarm parameter table, on the other hand, contains SPN (Suspect Parameter Number) and FMI (Failure Mode Identifier), which are utilized to check and compare whether alarms have occurred, and to cache alarm information.
Initializing the CAN peripheral involves several steps, including GPIO multiplexing, enabling the CAN clock, setting the CAN bus baud rate, and enabling CAN interrupts. To enhance CAN communication efficiency, CAN filter parameters can be calculated based on the PGN parameter table. The filter settings can be configured using a

combination of list mode and mask mode, allowing for more flexible and efficient filtering of CAN messages. The specific software process is illustrated in Figure 3:

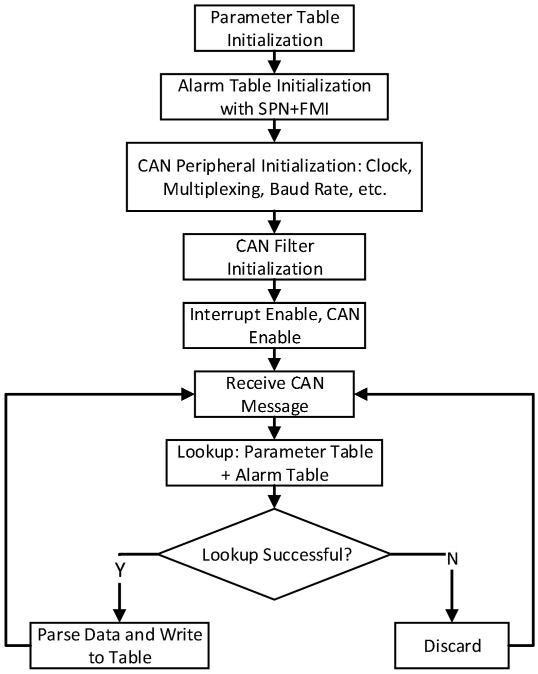

Figure 3 Engine Parameter Software Process Design

4 GENERATOR MODULE

The CAT3512B generator boasts exceptional power generation capabilities, with a rated power range between 1230 and 1500 kW, depending on its configuration and operating frequency. Its stable voltage and frequency output ensure the reliability of power quality, safeguarding the proper functioning of electrical equipment. Monitoring the generator's parameters is crucial for maintaining its safety, efficiency, and stable operation. It also facilitates the timely detection and resolution of potential issues, thereby safeguarding the reliability and continuity of power supply.

Based on the generator's real-time load conditions, its output power can be adjusted to ensure optimal operation within the desired load range, enhancing energy utilization efficiency. By optimizing the generator's operational parameters, such as fuel injection and rotational speed, it is possible to reduce fuel consumption and emissions, achieving energy-saving and emission-reduction goals.

This design incorporates an electrical parameter tester to collect various electrical parameters from the generator in real-time, including voltage, current, frequency, impedance, and power factor. The data collector retrieves the generator's parameters through an RS485 communication interface using the Modbus protocol, providing a reliable and efficient means of monitoring and managing the generator's performance.

4.1 Electrical Parameter Meter

An electrical parameter meter is an instrument used to measure and monitor various electrical parameters in circuits. It accurately measures parameters such as voltage, current, impedance, power factor, among others, assisting engineers and technicians in evaluating and optimizing circuit performance. Employing precise measurement technology, the electrical parameter tester boasts high resolution and low measurement error, catering to applications requiring high precision.

The electrical parameter meter covers a wide range of measurements, including voltage, current, frequency, impedance, power factor, and supports various measurement modes like real-time measurement, peak measurement, and root mean square (RMS) measurement to meet diverse application requirements.

The generator parameters are outlined in the following table 3:

Table 3 Generator Modbus Parameter Table

Parameter Name	Modbus Address	Data Length	Resolution	Description
Voltage (AC RMS)	40001	2 bytes	0.1 Volt	Root Mean Square AC Voltage
Current (AC RMS)	40003	2 bytes	0.1 Ampere	Root Mean Square AC Current
Frequency	40005	2 bytes	0.01 Hz	AC Frequency

Power Factor	40007	2 bytes	0.001	Power Factor
Impedance (Real Part)	40009	2 bytes	0.1 Ohm	Real Part of Impedance
Impedance (Imaginary)	40011	2 bytes	0.1 Ohm	Imaginary Part of Impedance
Active Power	40013	4 bytes	1 Watt	Active Power (Real Power)
Reactive Power	40017	4 bytes	1 VAR	Reactive Power

RS485 bus is a widely used serial communication protocol standard that employs differential signal transmission to effectively suppress common-mode interference, enhancing data transmission stability and reliability. Even in complex electromagnetic environments or high-noise scenarios, the RS485 bus maintains excellent communication quality. When using twisted pair cables as the transmission medium, the RS485 bus can achieve transmission distances of up to several kilometers, with a maximum distance of 15km at a transmission rate of 9600bps. The RS485 bus flexibly supports up to 32 transceivers, facilitating the establishment of device networks where bus control rights can be allocated through master polling or token passing, meeting communication needs in various scenarios and complex networks.

The Modbus protocol is a widely adopted communication protocol in the industrial control field. The communication network typically adopts a master-slave structure, where the master polls multiple slave devices to obtain their data. The Modbus protocol exhibits excellent fault tolerance and reliability, ensuring stable operation in complex industrial environments and transmission reliability.

4.2 Software Design for Generator Parameter Acquisition

A generator parameter table typically includes details such as the Modbus address, data length, and resolution for each parameter. These parameters are periodically acquired from the electrical parameter tester (EPT) via the RS485 interface using the Modbus protocol through a polling mechanism. The response message, once validated through data checks, is then written into the generator parameter table. The specific software process is illustrated in Figure 4:

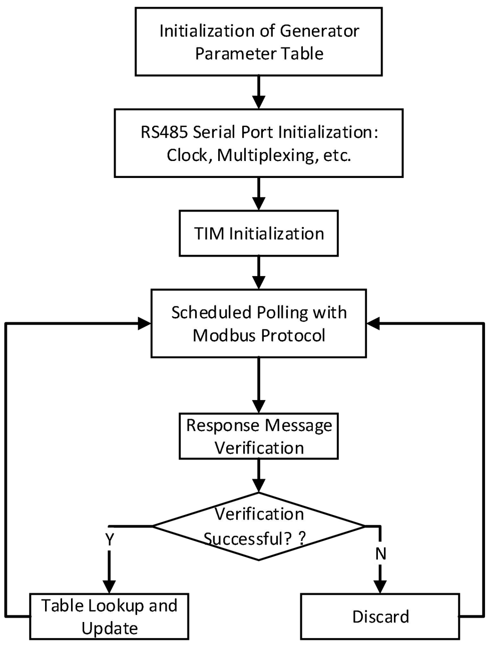

Figure 4 Generator Parameter Software Flowchart

5 DATA TRANSMISSION MODULE

NB-IoT, as a low-power, narrowband wireless communication technology, boasts broad application prospects and significant technical value in the Internet of Things (IoT) field. NB-IoT devices can achieve long-range transmission and large-scale connectivity with low power consumption[5], offering higher coverage gain than traditional GSM networks. Moreover, both the module cost and communication operating cost of NB-IoT are relatively low, facilitating the popularization and promotion of IoT. Employing multi-layer encryption mechanisms, NB-IoT ensures the security and privacy protection of data during transmission.

NB-IoT is widely applied in various sectors, including but not limited to logistics and warehousing, consumer devices, smart manufacturing, public utilities, healthcare, smart cities, and agricultural environments[6][7][8].

When integrating NB-IoT with an STM32F103 microcontroller, the two communicate via a serial port. This serial communication is used to initialize the communication parameters of the NB-IoT module, establish device connections, and connect the device to a data center or cloud platform. During operation, the device's sensors or collectors periodically report engine and other relevant parameters to the system through the NB-IoT connection, ensuring timely and reliable data transmission. The software process for data remote transmission is illustrated in Figure 5:

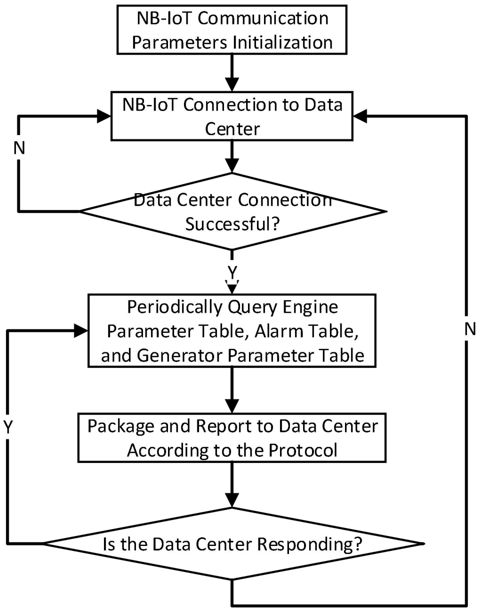

Figure 5 Data Remote Transmission Software Flowchart

6 CONCLUSION

This paper presents a design scheme for a CAT3512B diesel generator set data acquisition unit based on STM32, which realizes remote real-time monitoring of diesel generator equipment and provides data support for subsequent preventive maintenance. This scheme boasts low cost, high reliability, easy expandability, and low power consumption, making it widely applicable for similar equipment to achieve data collection, processing, and transmission. In the future, we will further optimize the performance and functionality of this device. By enabling real-time monitoring of operational parameters and warning information, it will not only prevent equipment failures but also play a vital role in enhancing equipment efficiency and safety, reducing maintenance costs, supporting remote operation and maintenance, and providing data visualization and decision support. These features collectively constitute an essential component of modern industrial production and equipment maintenance.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

REFERENCE

[1] Hongwei Guo, Tuo Yang. Design and implementation of an intelligent car obstacle avoidance system based on deep learning. Electronics Science Technology and Application, 2023, 10(2).
[2] Xuhai Wang, Weiguo Li, Lili Wang, et al. Based on STM32F103 cowshed environment intelligent control system. IOP Conference Series: Materials Science and Engineering, 2020, 782(5).
[3] Alzahrani Ahmad, Shriya Makarand Wangikar, Vairavasundaram Indragandhi, et al. Design and Implementation of SAE J1939 and Modbus Communication Protocols for Electric Vehicle. Machines, 2023, 11(2) : 201-201.
[4] Xuan Shao, Xingwu Kang, Xuping Wang et al. Design of special vehicle condition monitoring system based on J1939. Journal of Physics: Conference Series, 2020, 1549(3) : 032092.
[5] Jun Wang, Ting Ke, Mengjie Hou, et al. The Design of Home Fire Monitoring System based on NB-IoT. International Journal of Advanced Computer Science and Applications (IJACSA), 2022, 13(5).
[6] Ernesto Sanz, Jorge Trincado, Jorge Martínez, et al. Cloud-based system for monitoring event-based hydrological processes based on dense sensor network and NB-IoT connectivity. Environmental Modelling and Software, 2024, 182: 106186-106186.
[7] Lin Qingyao, Gao Qiuhong. Electric bicycle battery management system based on NB-IoT. 2024.
[8] Jun Lin, Xiaobin Xu. Design of a textile storage environment fire detection system based on ZigBee and NB-IoT. Journal of Physics: Conference Series, 2024, 2797(1).