Battery supervision system based on NB-IoT cloud

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ABSTRACT

Based on the current safety relationship of new energy vehicle batteries, this paper proposes a battery supervision system based on NB-IoT cloud. In this paper, the current state of battery charge in the pool is estimated by establishing a parametric model combined with the extended Kalman filter algorithm, so as to obtain various safety indicators and nonlinear parameters of the battery of electric vehicles, and real-time monitoring and timely adjustment of the use state and running state of the new energy battery, so as to improve the efficiency of the battery and extend the life of the battery. Aiming at the problem of fault diagnosis and safety regulation during battery use, this paper adopts the combination of multiple evaluation indicators, and realizes the termination and fault adjustment of the operation process by setting parameter threshold and interrupt procedure, so as to ensure the safety and stability of the operation process. In this paper, the upper computer system is designed to complete high-speed interaction and data storage of various parameters of external modules and battery fault diagnosis through NB-IoT cloud, so as to realize accurate supervision of batteries in the new-energy vehicle group.

Keywords:BMS management; NB-IoT cloud platform; Kalman filter; Fault diagnosis

1. BACKGROUND AND SIGNIFICANCE

Nowadays, with the rapid rise of new energy vehicles, it is an inevitable trend for electric vehicles to replace traditional fuel vehicles. New energy vehicles have become the first choice for people to buy cars because of their advantages of energy saving, environmental protection, no pollution and high cost performance. At present, new energy vehicles are using the standards and specifications of conventional fuel vehicles currently in use. At the same time, the management department is also developing targeted programs according to the characteristics of various aspects of new energy vehicles [1]. In the future, new energy vehicles will also play an increasingly important role in people's travel life, and its growth trend is shown in Fig. 1 below.

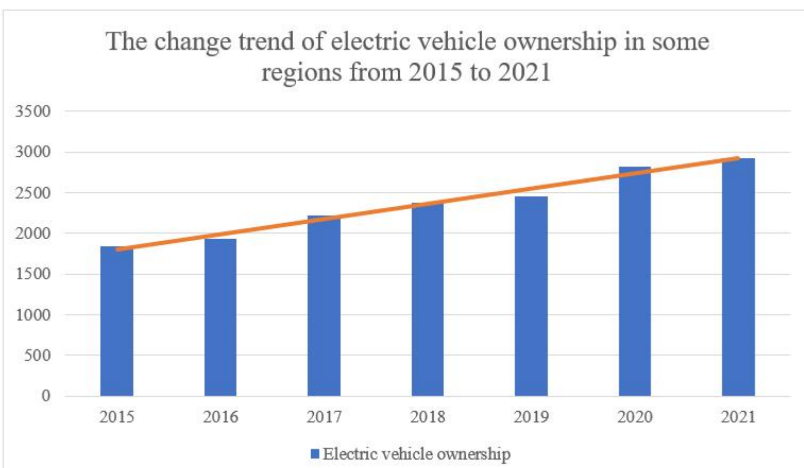

Figure 1. Growth of regional electric vehicle sales from 2015 to 2021

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With the increasing number of new energy vehicles, the existing problems also need more attention. In addition to the serious battery loss caused by the influence of external temperature, battery safety and stability can't be guaranteed and other problems are also increasingly prominent. Therefore, the battery management of new energy electric vehicles is an important research direction in the field of new energy vehicles at present. The research focus of new energy vehicles is to monitor the battery management system so as to explore the running state and safety state of the on-board battery. It can realize the data index monitoring of the vehicle running safety and battery evaluation parameters, especially some nonlinear parameters in the process of battery charging and battery use of new energy vehicles can be effectively monitored, so as to improve the efficiency of the battery. Prolong the battery life and ensure the efficient, safe and reliable operation of electric vehicles. In order to improve the performance of the battery and improve the life of the battery as far as possible while the safety problems in the use of the battery, each battery must be strictly managed in the use of the process, which foreign researchers have invested a lot of research on the monitoring of battery BMS system. In 2015, Garg A et al. developed a supervision system for new energy electric vehicles that can monitor according to the power system and battery working state of new energy vehicles, so as to realize remote alarm, intelligent unlock, rescue navigation and other functions[2]. The system innovatively adopted remote data transmission to classify and analyze different series of electric vehicles. In 2015, Jia et al., aiming at the current detection problem of new energy vehicles, proposed the use of GPRS communication technology to monitor and transmit vehicle data of new energy vehicles in running and charging state[3]. For the first time, remote server was used for data storage, which could greatly increase the transmission rate of the entire data transmission system. Ensure the timeliness of data transmission. While the domestic new energy vehicles started late, but with the support of related technologies, the domestic research on the remote monitoring system of power battery is also developing rapidly. In 2017, Liu et al. combined the on-board battery safety monitoring system of new energy vehicles with the Internet of Things, and proposed a remote monitoring system of the power system of new energy vehicles[4]. By setting information transmission terminals on both sides, data information transmission and processing were carried out, and data parameter collection and command operation tasks of the automated on-board system were completed. In 2018, Lin et al. proposed an electric vehicle power monitoring system based on 5G module in view of problems such as weak processing capacity and long processing time of the current fault warning system of electric vehicles[5]. The system can monitor a number of on-board information, including power system parameters, vehicle running speed, external environment temperature and so on. In addition, data is sent through specific communication protocols, and data processing and power system fault processing are finally carried out through the set system cloud[6].

Based on the above research status, aiming at the design problem of battery management system BMS for electric vehicles, this paper designed a cloud supervision battery management system based on NB-IoT to realize the rapid signal sampling, signal processing, high-speed data transmission, data processing and data return processes of the power battery system for new energy vehicles. In this paper, the SOC estimation algorithm combined with parameter filtering is used to estimate the battery parameters of a single power battery system. At the same time, in the aspect of communication, the CAN communication module is used to realize the remote control of the upper computer system, so as to ensure the accuracy and stability of the system data transmission[7]. Narrowband Internet of Things technology is used to upload battery pack data to the cloud in real time to realize comprehensive management of vehicle battery data, so that the status of each new energy vehicle in the convoy can be monitored in real time when the convoy is moving.

2. RESEARCH PROGRAM

2.1 SOC parameter estimation

As battery charging and discharging is a complex and unpredictable electrochemical reaction process, and lithium-ion battery as a single battery in battery pack has nonlinear characteristics, it is difficult to estimate SOC dynamically, real-time and accurately. Therefore, it is necessary to optimize the collection accuracy of the total voltage, total current, individual voltage, internal resistance and other parameter information of the battery. By constructing a parametric nonlinear model, the natural extended Kalman filter algorithm is designed to accurately estimate SOC parameter data, so as to carry out subsequent macro adjustment[8]. In this paper, the nonlinear relationship between SOC and various battery indexes was used to estimate SOC. The variation curve of SOC with voltage is shown in Fig. 2.

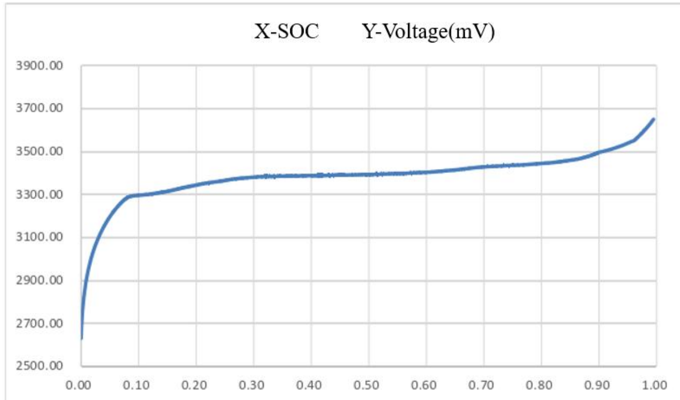

Figure 2. Relationship between battery voltage and SOC

This paper refers to the current traditional estimation methods, among which the relatively simple open-circuit voltage method, ampere-hour integral method and internal resistance method, but these three methods have advantages and disadvantages. Although the open-circuit voltage method is accurate in measurement, it can only measure the SOC at static, while the ampere-hour integral method has a wide range of application, but it will accumulate errors in the whole process of measurement, and especially depends on the accuracy of the initial value. However, the internal resistance method has a high precision in the late discharge stage, but the resistance is easily affected by external factors. In a comprehensive consideration, this paper decides to achieve accurate estimation of SOC based on Kalman filter algorithm. Kalman filter is initially applied to linear systems, but if the nonlinear systems are first treated linearly with Taylor formula, extend Kalman filtering to nonlinear systems [9].

The system calculates the input and output power of the battery pack in real time by amp-hour integration method. After real-time measurement for a certain period of time, the remaining power and SOC of the battery at the current moment are estimated at last. The calculation formula is shown in Eq. (1):

$$\mathrm{SOC}_k = \mathrm{SOC}_{k-1} + \int_{k-1}^{k} \eta * \frac{i(t)d_t}{Q_N} \tag{1}$$

η is the charge and discharge rate of the power system, and Q is the rated total electric quantity of the power system. By monitoring the input voltage and output voltage of the power system at the current moment and then integrating and correcting errors, the current electric quantity passed by the whole power system can be obtained. Since the electric quantity has a nonlinear relationship with SOC, the current SOC value can be obtained through calculation [10].

2.2 Kalman filter method

In this paper, Kalman filter method is used to compare the input and output of the power system, so as to make up for the errors caused by time sequence problems. In view of the nonlinear characteristics of different evaluation parameters, fitting calculation method and evaluation parameters should be selected to ensure the fitting curve fit in the process of estimating the residual capacity of the power system. In the actual monitoring process, historical data need to be compared to obtain the accurate standard of system parameters [11]. The current real value needs to be superimposed with the estimated value and historical value, so as to reduce the random error and system principle error in the monitoring system. The calculation formula of SOC by Kalman filter designed in this paper is shown in Eq. (2) and Eq. (3) below.

$$x_{k+1} = A_k x_k + B_k u_k + w_k = f(x_k, u_k) + w_k \tag{2}$$

$$y_k = c_k x_k + v_k = g(x_k, u_k) + v_k \tag{3}$$

Where, x_k is the SOC under the current state of the power system, and v_k is the voltage output under monitoring conditions. Considering the nonlinear parameter changes, $f(x_k, u_k)$ and $g(x_k, u_k)$ are selected as the nonlinear fitting curves of the system battery, and then the real SOC is calculated by matrix estimation and error superposition cancellation[12]. The specific calculation is shown in Eq. (4).

$$SOC_{k+1} = SOC_k - \frac{\eta(i_k) i_k \Delta t}{C} \tag{4}$$

To realize the safety protection and state regulation of abnormal state of automobile battery

In BMS system, fault diagnosis and treatment of vehicle system is the key to ensure the normal running of vehicle. Battery faults are mainly divided into general cases and accident failures, which will not affect car driving in general cases, and may be caused by excessive temperature difference of the system power storage and transmission problems or internal signal detection system problems, excessive temperature difference and information acquisition unit failures. For such faults, timely alarms need to be issued. And for the accident fault may cause the power system to stop running and cause danger. Therefore, it is necessary to estimate and analyze the battery status in the BMS system, and reduce the cloud data processing time and error [7].

3. DESIGN OF POWER BATTERY SAFETY MONITORING SYSTEM

The battery power management system designed in this paper is mainly divided into two parts: sampling design of hardware part and software communication design. The data sampling unit of hardware part is equipped with multi-body battery stack monitoring chip to collect the voltage of single battery stack and other data. The software communication part is mainly used for data reception and cloud data transmission [11]. The Internet of Things module is used to communicate between system boards through CAN bus. In the data processing part, SOC estimation algorithm based on extended Kalman filter algorithm is adopted. Meanwhile, battery data is uploaded to the cloud via NB-IoT module to realize cloud monitoring. Fig. 3 below is the system operation block diagram.

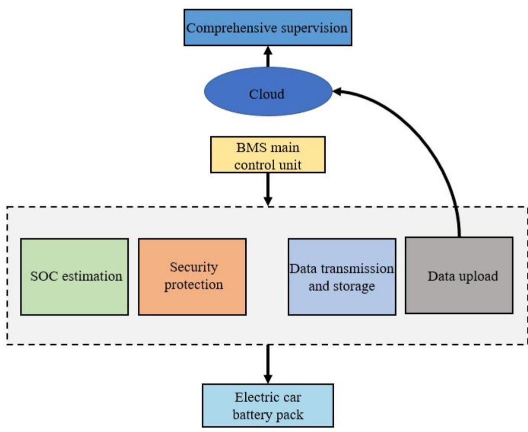

Figure 3. Overall block diagram of the system

The hardware part is mainly used for SOC related parameter measurement and system numerical evaluation, and transmits the collected data to the control terminal through the on-board Iot module of the vehicle terminal receiving device. The hardware part is mainly composed of main control module, data sampling unit module, vehicle terminal receiving device module, power module and remote control module.

3.1 Main control module

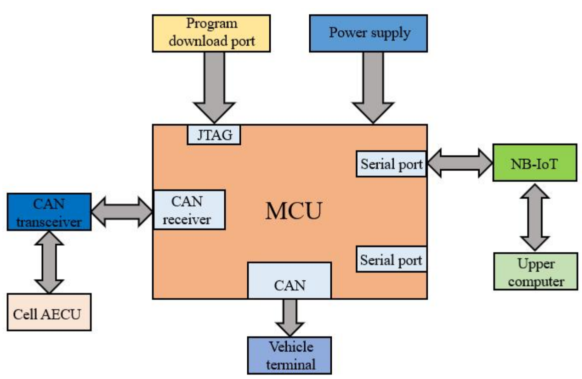

Figure 4. Overall block diagram of the hardware master of the vehicle system

According to the communication structure diagram of the main control module in Fig. 4, the main control module is mainly composed of the main control system, peripheral circuit and external serial port information input terminal. The tasks in this paper mainly include SOC estimation, early warning system control signal reception and fault interrupt control. The main control chip is the core of the main control unit and the computing and logical processing unit of the cloud battery monitoring system, which can receive and process the collected data information in real time. In terms of monitoring and adjustment, the specific functions of the main control system are as follows: the main control system receives the battery pack data collected from the front end through the CAN bus reading and writing acquisition management unit AECU, and transmits it to the remote upper computer line for display and output through the communication module [9]. At the same time, it can also control the running state of the electric vehicle after receiving the control signal. To sum up, the main control module has complex working conditions and a large amount of computation, so the selection of the main control module is of great significance to the real-time and stability of the whole system.

According to the data sampling and communication requirements and design indicators of the battery safety monitoring system on the NB-IoT cloud platform in this paper, MPC5604 is selected as the main control module of the system, which can meet the following requirements of the monitoring system:

1. Multi-channel CAN controller: It can control multiple serial ports at the same time to ensure the stability of the device and operation during the sampling process of the battery system.

2. Sufficient peripheral ports and communication ports: to meet the output of detection unit signals and communication signal reception.

3. Low power consumption, good real-time performance, strong computing ability: ensure the battery safety monitoring system in the monitoring work of electric vehicles for a long time to work stably.

3.2 BMS Data sampling unit module

In the development of BMS, two design structures are mainly used: centralized and distributed. There are fewer wires in the centralized system, but all the functions of the system are concentrated together, which not only causes the system to be too large, but also easily causes the chaos of the system functions, which is not conducive to development and maintenance. In the distributed system, there are many connections between the units, and the excessively dispersed function modules are easy to cause the high coupling between the units, which increases the complexity of the whole system.

In this paper, the advantages of the two schemes are compared and combined, and the BMS hardware system is divided into acquisition unit, management unit and cloud system by the scheme of decentralized data acquisition and centralized processing.

1. BMS acquisition unit

The BMS acquisition unit uses MC9S12XET256 as the main control and the battery stack monitoring chip LTC6804-2 to measure the voltage of the single battery in the battery pack with high precision. The master controller and the battery monitoring chip conduct data interaction through SPI, configure registers related to collection, and receive the returned data after completion of collection. Multiple collection units CAN transmit battery pack data to the BMS battery management unit through the CAN bus for subsequent processing.

2. BMS management unit

The BMS management unit uses MPC5604 as the main control, detects the total current in the battery pack trunk through the current sampling circuit, and uses the CAN bus to receive the voltage data of a single battery transmitted by the BMS acquisition unit for data processing. The master controller interacts with the NB-IoT module and uploads battery pack data to the cloud through the module.

3.3 NB-IoT module

The NB-IoT wireless communication module of the vehicle terminal is used to upload the data collected by the vehicle terminal to the cloud monitoring platform, or receive the update program issued by the cloud monitoring platform. In this paper, the on-board terminal uses the BC-26 module, and the main control chip is the MT2625 chip. The BC-26 module has the characteristics of low cost and high performance, and contains the multifunctional external interface and the protocol stack related to network communication. It can support the Internet of Things platform adopted in this paper, thus greatly improving the transmission and reception rate of the sampled data of the system.

The performance parameters of the BC-26 are as follows: The voltage supply range is 2.1 to 3.6V. Generally, the voltage supply is 3.3V. The typical current consumption of PSM is 3.5μA. Multi-band LTE support; Support TCP/UDP/MQTT and other Iot protocols; Support AT instruction control; The upstream transmission rate is 25.5Kbit/s, and the downstream transmission rate is 62.5Kbit/s.

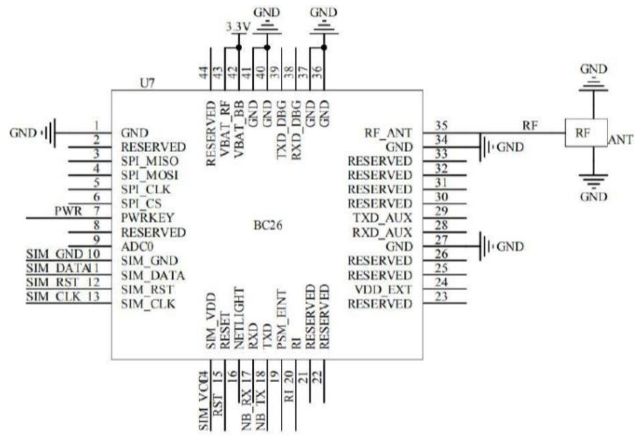

Figure 5. External circuit of NB-IoT module

The external circuit of NB-IoT module designed in this paper is shown in Fig. 5. BC-26 adopts TTL level serial communication. During signal transmission, it only needs to connect the PWK pin to 3.3V, and the NB_RX and NB_TX pins are directly connected to the serial port of MCU and co-located, so as to realize the data communication between NB module and MCU. The external voltage conversion circuit is shown in Fig. 6 below.

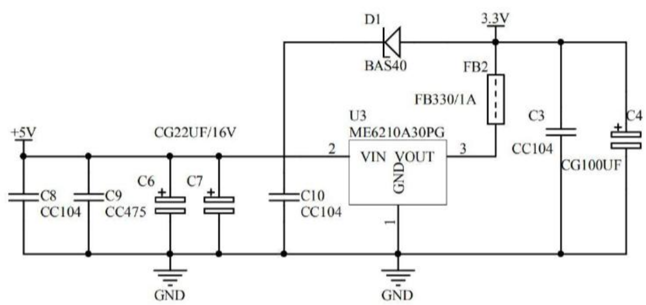

Figure 6. Voltage conversion module of external circuit

The NB-IoT Internet of Things module is adopted to obtain voltage data of each unit from the management unit and upload it to the cloud interface, so as to monitor and manage the battery status of the whole new energy fleet on the mobile phone or PC APP.

3.4 Modeling and simulation of battery model

The structure of the battery is relatively simple, but it is a complicated nonlinear electrochemical change in the actual working process. Building a battery model can provide a method to simulate and measure the electrochemical changes of the battery during operation, shorten the measurement time of experimental parameters, and also provide the safety of the test. At the same time, accurate battery mode is the basis of SOC estimation.

In this paper, MATLAB Simulink was used to build the battery pack model and conduct simulation analysis. Central difference Kalman filter algorithm was used to process the voltage and current acquisition data of the battery pack. Considering the joint distribution of each measurement value at each time, the estimation results of unknown variables were more accurate than the method based on a single measurement value. The Stirling interpolation formula is used to approximate the derivative of the nonlinear equation by polynomials, which is more suitable for the variation of the nonlinear parameters of the battery model.

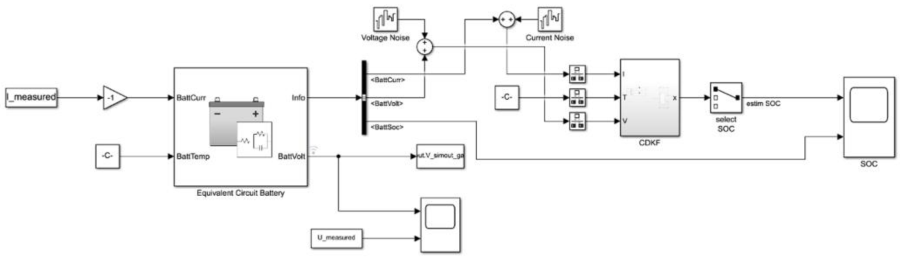

Figure 7. Simulink battery model and simulation of SOC estimation

The simulation model is shown in Fig. 7. The breakpoints of different SOC states of the battery model are set. At the breakpoint, the battery pack open-circuit voltage and load current change parameters are taken as inputs to carry out CDKF algorithm processing. Then, the theoretical SOC value of the battery pack is calculated using the SOC estimation algorithm, which is compared with the actual SOC value of the breakpoint to verify the accuracy of CDKF estimation of the battery SOC. Thus, a high precision SOC estimation system for battery model based on central difference Kalman filter is obtained.

3.5 Design of vehicle terminal receiving device

1) Setting of vehicle terminal Transceiver device

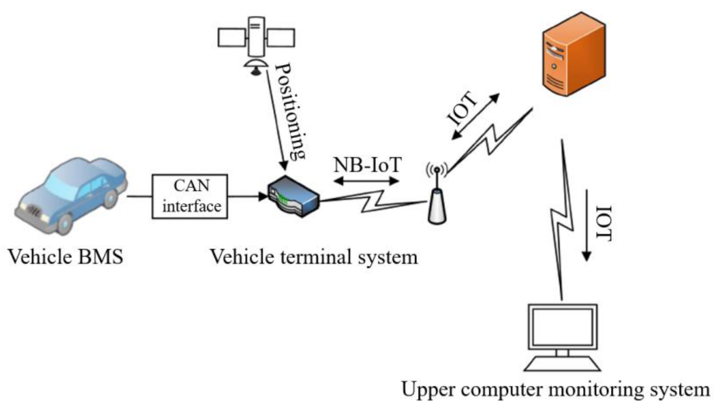

Figure 8. Logic diagram of vehicle system data sending and receiving

As can be seen from Fig. 8, the on-board NB-IoT-BC26 iot module of the vehicle terminal receiving device transmits the sampled data information of various parameters of the power battery system to the main control terminal in real time through communication between the 5G industrial router and the remote control box, realizing accurate control of the battery system. The operating information of the battery system is collected by means of cloud service, including the operating mode, real-time operating status of the system, storage of system history records, fault waveform when the system is grounded fault, etc., to realize hierarchical management of the running status of the electric vehicle at different times and in different running states. The running logic of the vehicle terminal receiving device is shown in Fig. 9.

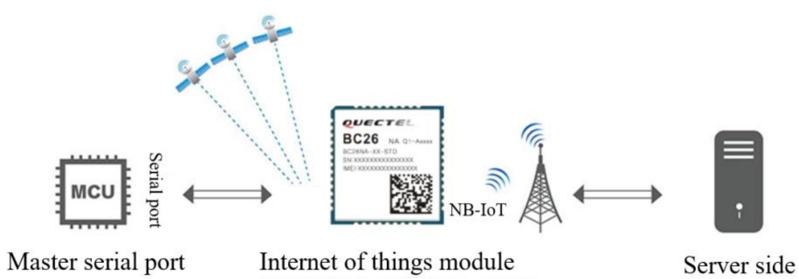

Figure 9. Installation diagram of vehicle receiving terminal

2) Division of functions between vehicle terminal and remote controller

The vehicle terminal receiving device can receive the signal from the wireless control box E34-2G4H20D module and the remote control signal in the network, and feed back the working state and output power of the battery power system to the remote control terminal in real time. After GPS realizes satellite positioning, GPSR sends the longitude and latitude, speed, azimuth and altitude data of the monitored target back to the monitoring center. Here, HTTPD Client mode is adopted. The main control communicates with the USR-GM3P Internet of Things module through serial port, and USR-GM3P communicates with the remote control side web server through 5G network through module, and data is stored and analyzed in the database SQL.

4. SOFTWARE COMMUNICATION AND EXPERIMENTAL VERIFICATION

In the embedded system in this paper, in order to complete the wireless measurement and control function, the GSM module needs to cooperate with the processor, and finally achieve the functions of information acquisition, information processing and information instruction. Therefore, the internal processor of this system uses the hardware circuit and the software computer to combine the way to achieve the safety performance of the power system, to ensure the effectiveness and stability of the system, through the external circuit of the way to achieve the processor operation control. The software design architecture of the vehicle terminal is shown in Fig. 10 below

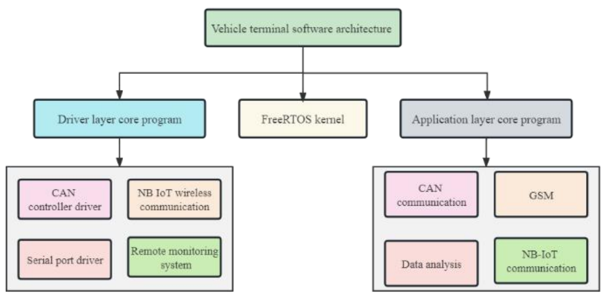

Figure 10. Software design architecture of vehicle terminal

The core program of application layer needs to design corresponding CAN communication program to complete the function of collecting power battery working condition data. The Internet of Things module communicates with MCU through serial port and automatically sends the current location information, so there is no need for driver to control the Internet of Things module. The core program of the application layer needs to design the data analysis program to complete the function of analyzing the location information of the vehicle. For data transmission function, the communication interface between NB-IoT and MCU is serial port. It is necessary to design NB-IoT wireless communication driver to call serial port and complete the initialization of NB-IoT module. The core program of the application layer needs to design the NB-IoT communication program, so that the NB-IoT module can establish wireless communication with the cloud monitoring platform, complete the function of uploading data to the cloud monitoring platform and receiving the update program issued by it. For the operating system function, according to the characteristics of the system communication, tailoring the required system function, and in the process of application design, complete the transplantation of the operating system.

4.1 CAN communication

CAN bus communication module mainly completes CAN node initialization, data sending and receiving. Initialization is to initialize BC26 communication module and carry out related controller configuration. When sending, the data to be sent is first combined into a frame according to the format of CAN message and sent to the BC26 communication module sending cache. Then the data is sent to the CAN bus through the corresponding sending command. When receiving, the data sent is first stored in the receiving buffer of the GSM communication module, then the value of the buffer is received and saved through the corresponding receiving command, and finally the receiving buffer is released.

4.2 Initializing the CAN communication function

Initializing the CAN communication function includes configuring the I/O function. Set the working mode (common mode and cyclic mode), baud rate (CAN data transmission rate) and identifier ID of CAN controller (since BMS uses the extension frame of CAN2.0B protocol, 29-bit identifier ID needs to be set), etc. The specific operation process is shown in Fig. 11 below.

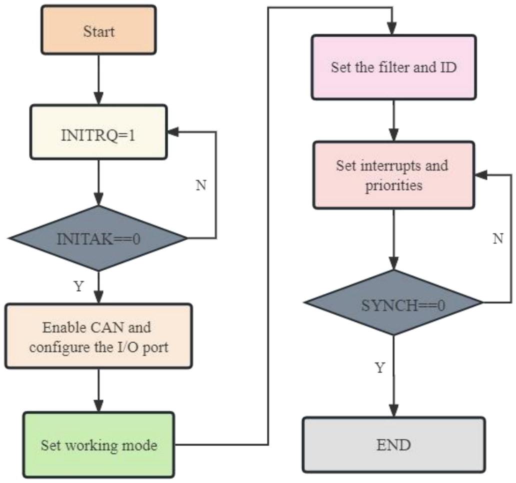

Figure 11. Specific operation process

First, the program queries and controls the register INITRQ bit configuration to 1, entering the initialization mode of the CAN controller. Then, determine whether the INITAK bit is 0. If it is 0, it means that the program has entered the CAN controller initialization mode; if it is not 0, it waits. Next, the program filters out irrelevant messages on the CAN bus by setting two 32-bit filtering registers, and sets the 29-bit identifier ID. Then enable the CAN receive interrupt for processing the data received by the CAN controller. Finally, whether the SYNCH bit is 0 determines whether the CAN bus clock is synchronized. After the initialization is complete, make the CAN controller exit the initialization mode and enter the normal mode. The CAN controller will run normally under the set working parameters.

4.3 Experimental demonstration

This system uses GUI interface as the upper computer of system monitoring, GUI communicates with the central control chip master in this system through AT instruction, AT is Attention, AT instruction set is sent from terminal device or data terminal device to terminal adapter or data terminal device. Through TA,TE sends AT commands to control the functions of the mobile station and interact with GSM network services. Users can adjust the battery monitoring system and fault alarm through AT instruction, so as to realize real-time monitoring of the battery system. AT instructions must begin with "AT" or "at". The specific debugging results are shown in Fig. 12.

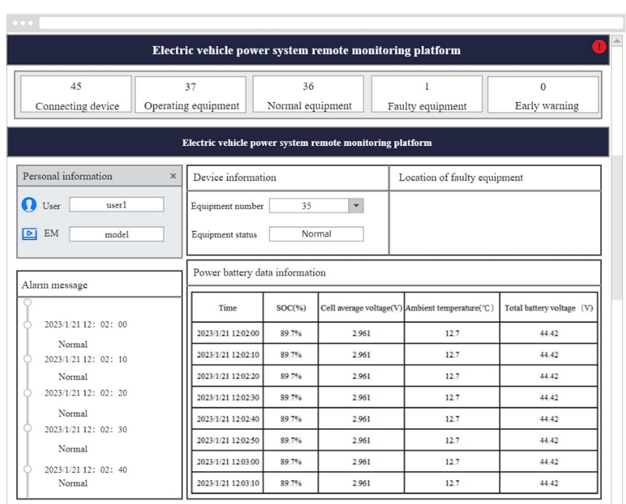

Figure 12. Battery safety monitoring system experiment diagram

5. CONCLUSION

Based on the current status of battery pack monitoring for electric vehicles, this paper proposes a battery monitoring system based on NB-IoT cloud. The system mainly samples each parameter of a single battery through the BMS sampling unit, then obtains the output voltage and input voltage of the current driving battery through signal processing and data conversion, and obtains the SOC value of the current state of the power system through data iteration and parameter setting. At the same time, the sampling unit detects the total current in the battery pack trunk through the current sampling circuit of the power system through the main control MCU. Data is transmitted to the NB-IoT cloud system combined with the GSM communication system and CAN bus in the system, and the system carries out data processing and threshold limitation. The current parameters are divided to obtain the motion state of the power system and timely feedback to the supreme machine system to ensure the stability of the electric vehicle operation.

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