Design of power well cover wireless monitoring system based on freeRTOS and NB-IoT technology

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Abstract. Power well cover monitoring system (PWC-MS) based on the embedded microprocessor ARM Cortex-M3 with FreeRTOS is proposed in this paper. The software functions of the terminal are divided into four tasks, namely, watchdog refresh and flag monitoring task, system status light task, non-debug sensor mode task, and debug sensor mode task. The priority levels of tasks depend on real-time requirement. The temperature and humidity sensor RS-WS-N01-2-2 and the dual-axis tilt sensor ADXL345 are adopted in the terminal and the sampling data is sent to the IoT (Internet of Things) platform via the NB-IoT communication module BC35-G. The software of application layer in the IoT platform is developed based on the Spring Cloud and database technology with Java language. User can get the real-time data through the Web page. Experiments show that the PWC-MS works well and the real-time alarm can be realized immediately.

Keyword: FreeRTOS; ARM; power well cover; wireless monitoring system; NB-IoT

1. Introduction

Currently, the construction of smart grid is in full swing. The urban pipeline is an important part of urban planning and construction. Gradually, it is a trend that the overhead lines are transformed into underground pipeline [1]. Nowadays, a large number of high-voltage cable well covers in the UPG are still under the management of manual inspection. The manual inspection is not only heavy work load, but also is hard to respond power well abnormal information quickly [2]. These cause a great security risk to vehicular and pedestrian, which brings a great challenge to the safety of UPG and citizens[3]. How to carry out real-time monitoring on well covers and deal with the abnormal situation quickly to guarantee the safety of the citizens and power assets is an urgent problem to be solved for the electric power department.

Meanwhile, FreeRTOS is completely free even in commercial scenarios [4]. It analyzes the principles of FreeRTOS and μc/OS-II kernels. It turns out that FreeRTOS has unlimited tasks and more flexible scheduling strategies [5]. There are also many researches on IoT monitoring applications based on FreeRTOS, including intelligent power monitoring, downhole multi-parameter recorders and smart home solutions [6]. Therefore, in order to solve monitoring management, safety problems in daily operation of power well covers in the urban power tunnel and make it easy for maintainer to obtain power wells condition such
covers states and detailed surrounding information in the cable wells. The power well cover monitoring system (PWC-MS) with embedded microprocessor STM32 and real-time operating system FreeRTOS by employing NB-IoT wireless communication network for remote data transmission is proposed in this paper, which can monitor the power well states, realize early warning and ensure power and road safety.

2. Terminal hardware design of PWC-MS
The data processing of the power well cover monitoring system is based on the data uploaded by the monitoring system terminal to the IoT platform. Therefore, the most important part of the system is to realize real-time, accurate collection of sensor data and upload it to the cloud server. In addition, considering the large distribution of power wells, a large amount of data is distributed in various hidden and complex surroundings such as basements, equipment rooms, streets, underground pipelines, tunnels, markets, and building rooms. This means that the power well monitoring system terminal must work for a long time while accurately collecting data in real time.

Based on the above requirements, the hardware design of the power well cover monitoring system terminal is based on the STM32L151C8 microprocessor. The hardware structure block diagram of the power well cover monitoring system terminal is shown in Figure 1.

![Figure 1. PWC-MS terminal hardware structure block diagram](image)

2.1 Sensor selection
Temperature and Humidity Sensor (THS): The type SHT20 is adopted as THS. Humidity accuracy 3% RH. Humidity range: 0 ~ 100% RH. Temperature accuracy: ±0.3 °C. Temperature range: -40 ~ 125 °C. Working power consumption: 4.8µA.

Dual Axis Tilt Sensor (DATS): The type ADXL345 is adopted as DATS. The ADXL345 is with high resolution, up to 13-bit resolution and variable measurement range sensitivity +/-2g, +/-4g, +/-8g, +/-16g up to 3.9mg/LSB. In addition, it can measure the tilt angle change of less than 1.0°. Most importantly, the ADXL345 possess ultra low power consumption of 40~145µA and is only 0.1µA during standby mode.

2.2 Communication module
The BC35-G module is adopted as the NB-IoT wireless communication module, which is characterized by ultra-low power consumption and ultra-high sensitivity. The power consumption is 3.6µA during power-saving mode, the working power consumption is 6mA, and the sensitivity is -129dBm±1dB. The module adopts LGC package which is easier to be welded and suitable for mass production. Using Quectel enhanced AT command and supporting Chinese Datagram Protocol (UDP) connection, BC35-G module enable accomplish data transmission and realize the interaction between cable well states information and IoT cloud platform.

2.3 Power circuit design
The power is a basic module that provides a stable energy supply to the system. It is mainly divided into two modes. One is battery powered and the other is powered by a 5V adapter.
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The first type power supply is powered by a lithium battery. The lithium battery provides 3.7V voltage through the capacitor filter, the SS34 diode outputs 3.5V voltage to the BC35 chip, and the other part through buck circuit outputs VCC_3V3 to the other modules of the circuit.

The second power supply mode is powered by a 5V adapter. The adapter provides a 5V voltage-stabilizing circuit to modulate output 3.7V, and then forms the entire power supply system through the same circuit as the first power supply. In addition, when using external 5V power supply, the circuit automatically switches to the battery charging mode. By connecting the external 5V power supply to the battery charging control chip, the battery charging control chip monitors the battery voltage and charges the battery.

3. Terminal software design of PWC-MS
The software design of the PWC-MS consists of two parts. One is the terminal software design of PWC-MS and the other is the software design of application layer.

In the PWC-MS, the terminal needs to complete a plurality of tasks such as system initialization, data acquisition, data communication, and system operation status indication. In order to ensure the real-time performance of the system, make more reasonable and effective use of CPU and transplant the FreeRTOS. So the task needs to be designed into several separate parts to be completed by PWC-MS. FreeRTOS is transplanted via STM32CubeMX visualization tool in this paper. After configuring the clock, serial port, I/O port and other parameters with STM32CubeMX, corresponding Keil project can be easily generated. Compared to traditional one, generating code with the STM32 CubeMX configuration is simpler, more convenient, and more errorless.

3.1 Main process of terminal software design
The terminal of the PWC-MS is mainly to collect the power well covers dip angle, temperature and humidity datum, then package them into data packets and upload them to the IoT platform through the NB-IoT wireless network. The main flow chart of the software is illustrated in Figure 2.
The above flow chart can be described as: initializing the STM32L151C8T6 chip and FreeRTOS after the system is power-on, and then starting the watchdog timer to provide protection for the system; Then the BC35-G module dials the network (detect the SIM card status, module status, query IMSI and IMEI number, attached network, etc.). If the BC35-G module network is unsuccessful less than 10 times, BC35-G will continue attach the network. Otherwise resetting the BC35-G module and redialling again. After the network is successfully attached, the sensors start collecting datum. Initially, the sensors datum are collected as the initial value sample based on the Grubbs criterion. Then, the sensor datum are collected every 5 minutes and judge theirs integrity. If datum are integrity, then move on next step, otherwise the system collect datum anew. After confirming sensor datum (dip angle, temperature and humidity) are in range of threshold or not. If datum exceed threshold value, the datum will be reported to IoT cloud platform through the BC35-G wireless communication module immediately, otherwise they will be uploaded every 30 minutes.

3.2 Task division and function design
The terminal program design of PWC-MS mainly includes four tasks: watchdog timing refresh, flag position monitoring, system status light, non-debug sensor mode and debug sensor mode. The specific functions are based on FreeRTOS embedded real-time operating system for task scheduling.

3.3. Application layer software design
In this system, the terminal data is uploaded to the IoT platform through the NB-IoT network. The platform is in the cloud and is carried in the server. Externally, the cloud platform only implements pure data processing services, does not involve interface implementation, and provides a unified API interface, so that each control platform can develop interfaces according to its own platform characteristics, and does not affect the implementation of functions. In order to realize the interaction between the user and the platform, the database needs to be designed on the server side to archive and store the data of the IoT platform. In order to realize the visualization of the data, the front-end technology is used to design the web interface, and the data that has been archived and stored is displayed in the form of a graph on the webpage side.

The server-side application project designed in the application layer is developed in Java language. Combining Spring Cloud technology and database technology, a Web-based monitoring platform has been developed.

4. Experiments
The physical map of the PWC-MS terminal is shown in Figure 3. The PWC-MS is packaged and installed on the simulated power well cover. After the system is power-on, the initial data is automatically collected ten times as the original parameters to obtain the initial values of the dip angle, temperature and humidity. After 3 hours of testing, open the client to observe the data flow. As shown in Figure 4-5, the platform can display various environmental data transmitted from the terminal of the PWC-MS in real time.

![Figure 3. Physical map of the PWC-MS terminal](image)

![Figure 4. Terminal temperature and humidity data flow](image)
The tests show that the terminal device can stably upload the sensors datum to the IoT platform, and users can view the data flow of sensors through the web page. Therefore, The PWC-MS based on NB-IoT and FreeRTOS can monitor environment information of the power well in real time. As a result, PWC-MS reaches expected effect and lays the foundation for realizing remote information monitoring of large-scale power well covers in urban areas.

5. Conclusion

PWC-MS based on NB-IoT and FreeRTOS embedded real-time operating system is proposed in this paper. The terminal system function is divided into four tasks including watchdog refresh, flag monitoring tasks, system status light tasks, non-debug sensor mode tasks and debug sensor mode tasks. After testing, the system shows stable operation and good real-time performance. What’s more, PWC-MS can accurately collect data in real time and upload it to the IoT cloud platform correctly. As a data acquisition terminal, its software design structure is clear and easy to rewrite, so PWC-MS can be applied to other industrial backgrounds as a node in the sensor network.

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