Design of NB-IoT smoke sensing terminal based on photovoltaic and supercapacitor power supply

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Abstract: The common smoke detection terminal designed for fire detection is mainly based on wireless communication technology and sensor technology. With the development and application of 5G technology in recent years, the Internet of Everything will become a historical inevitability. Compared with the traditional wireless networking technology, the application of NB-IoT technology can greatly reduce the power consumption and cost of the equipment, and also increase the service life of the equipment. Under the background of more and more mature communication network technology in the future, how to make the equipment more durable and lower power consumption has become one of the key issues to improve the performance of the equipment. Therefore, the power equipment charging with polycrystalline silicon photovoltaic cells and storing energy with supercapacitors can supply energy for the detection equipment continuously. The photovoltaic charging circuit uses the variable step length conductance increment method to track the maximum power point to improve the utilization rate of solar energy. As a communication technology, narrow-band IoT can reduce more power consumption. The narrow-band bandwidth allows devices to be widely placed in a fixed area. Under the premise of realizing the functional requirements, the principle of hardware and software design is mainly to realize the low power consumption in all aspects, and the design of the upper computer is mainly to realize the real-time understanding of the detection equipment.

1. Introduction

Campus-based fire prevention and control is an important aspect of fire prevention and control. Take our school as an example, the management mode of the campus is relatively lax. In recent years, it is often seen that fires are caused by students' heating, electricity use and food and drink. If the fire cannot be detected in the unmonitored area in time, the consequences and losses will be hard to estimate. It is very difficult to completely prevent the occurrence of fire, so it is of great significance to find the fire...
as early as possible from the source and remedy it in time to reduce the fire harm. Therefore, the school has also taken certain measures in fire monitoring, and the smoke sensor based on early warning is all over the campus.

At present, the traditional fire warning terminal mainly uses wireless communication technology and smoke sensing technology [1]. Recently, our school cooperated with the telecom company to arrange a smoke sensing terminal based on the narrow-band Internet of Things communication in the campus. The terminal can sense whether the smoke concentration in the air exceeds the standard to predict the occurrence of fire, alarm with a buzzer, and upload the information to the upper computer at the same time. Although the NB-IoT equipment has the characteristics of power saving, according to the theoretical test, the battery of the equipment laid out in our school can be used for about two years. Once the time limit arrives, the battery needs to be replaced in a large range. Due to the large number of nodes, it is necessary to hire people to disassemble and install the equipment, and the cost is higher at this time. As a renewable and recyclable energy, photovoltaic electricity is very suitable for the power supply of small and medium power electrical equipment. Independent photovoltaic system needs to be equipped with a certain capacity of energy storage device to ensure the continuous reliability of load and electricity [2]. ZhangLiYuan proposed a charging circuit combining solar energy and lithium batteries to supply power for communication and detection equipment, which solved the problem of continuous power supply [3]. However, as an energy storage device, lithium batteries have problems such as short cycle life, strict charging and discharging conditions and environmental pollution.

Based on the above two considerations, compared with the battery currently used in smoke detector, the combination of photovoltaic charging and supercapacitor, as a new direction in the field of energy storage, has a very good prospect for the development of low-power narrow-band IoT [4-6].

2. Overall system design
The design takes STM32 as the core control system, NB-IoT as the communication means, clean energy light as the energy supply, and supercapacitor as the energy storage equipment, aiming to develop a smoke detection terminal suitable for universities and other public places. The photovoltaic power supply system uses MPPT controller based on variable step length conductance increment algorithm to track the maximum power point of solar panels to improve the solar energy utilization rate. The solar panel output a stable voltage to power the device and charge the supercapacitor. The simulation analysis of the power supply design is carried out, and the power supply that meets the requirements of the system is obtained. Smoke sensor and NB-IoT integrated terminal as a monitoring system and communication system. The message is sent to the top computer through the cloud platform. At the same time, the upper computer can also take the initiative to issue instructions, real-time query terminal node state, human-computer interaction, if there is abnormal, can be real-time warning. The overall design architecture of the system is shown in figure 1.

![Figure 1. Overall design of the system](image-url)
3. System hardware circuit design

This design main hardware circuit has MCU peripheral circuit, NB-IoT module circuit, power supply circuit and so on. Considering the low power consumption, the selected hardware is mainly energy saving and low power consumption, and the circuit design is also for the purpose of power saving. STM32L431CCT6 is selected as the core control chip, NB-IoT communication module selects M5310-A module of China Mobile Internet of Things and MQ-7 smoke sensor.

3.1 STM32 peripheral circuit design

In terms of energy saving technology, the selected STM32L4 adopts the FLEX Power Control energy saving technology unique to ST. When the microcontroller enters the low-power mode, it can protect important data. All STM32L products also support batch processing mode, With the main CPU off, data can be collected and stored efficiently at low power consumption. The NB module is controlled by P18. The circuit is shown in figure 2.

![STM32 peripheral circuit diagram](image)

Figure 2. STM32 peripheral circuit diagram

3.2 NB module peripheral circuit design

The M5310-A uses low power technology, with current power consumption of 3uA in PSM mode. This module support band is B3 / B5 / B8, support network protocol IPv4 / IPv6 / Non-IP/UDP/TCP/CoAP/LwM2M/HTTP/ MQTT, this design uses LwM2M protocol, docking Huawei cloud IoT platform. NB-IoT module mainly includes M5310-A main chip circuit, SIM card circuit and antenna circuit. This design adopts the special antenna of NB-IoT module of M5310-A. In terms of peripheral circuit design of NB, the RESET function of M5310-A main chip can be realized through a MOS connection between MCU and M5310-A main chip. The peripheral circuit of NB module is shown in figure 3.
Figure 3. NB module peripheral circuit

The debugging interface is realized through P1 and P2 of M5310-A main chip. Switching TTL through USB can make NB module debug directly through PC, and can also monitor STM32 information interaction with NB module through PC in the process of work, which is convenient for debugging. Figure 4 shows the interface circuit.

Figure 4. Debug interface circuit

The power supply circuit of NB module is shown in figure 5. The power supply is directly connected to the VBAT pin of the power supply circuit. MCU controls MOS by output high level or low level to PWEN, so as to control the direct voltage input of pin RF_VCC to M5310-A.

Figure 5 NB module power supply circuit

3.3 Power circuit design

The design of the power circuit includes solar photovoltaic charging circuit, maximum power point tracking circuit, voltage and current detection circuit, supercapacitor charging and discharging circuit, Buck/Boost circuit, etc. Polysilicon solar photovoltaic cells are selected, which have the characteristics of simple process, low price, high photoelectric conversion efficiency and low energy consumption. The solar panel selected has a rated power of 3W, a maximum power voltage Vm of 6V, a maximum power current Im of 0.5A, an open-circuit voltage Voc of 8V, and a short-circuit current Isc of 0.8A. The discharge circuit of photovoltaic cell is shown in figure 6.
Choose rated capacity 50 f ultracapacitor monomer, six super capacitor in series to form a rated voltage 6v super capacitor group, consisting of a super capacitor group as a whole system of energy reserves, its discharge equivalent circuit as shown in figure 7, super capacitor voltage can be equivalent to ideal voltage of the capacitance and the equivalent series resistance of RES voltage difference [7].

4. Software design and simulation verification

In the aspect of program design, the low power consumption of hardware is considered. The monitoring software of upper computer is designed. The power supply circuit is simulated and verified. Combined with a variety of photovoltaic maximum power point tracking algorithms, the variable step length conductance increment method is selected to track photovoltaic maximum power. The low power function of NB module is further optimized to maximize the low power consumption of the terminal.

4.1 Terminal software design

In the aspect of terminal programming, if the program is simply run with bare computer, there will be delay cycle waiting function in multiple business logics, resulting in all business logics working in serial. This time delay function will waste a lot of CPU time, which will keep idling, resulting in low concurrency efficiency of the software. Based on this consideration, the terminal software design is carried out under the Ucos system.

4.1.1 Data acquisition program design

The first step is to initialize the smoke sensor peripheral, initialize ADC, and start ADC sampling in the main task. The sensor 5s is sampled once, and the average value is calculated once every 10s. The result is compared with the set threshold value. The program flow of smoke data collection is shown in figure 8.
4.1.2 NB communication module software design

This design M5310-A module is connected with Huawei Cloud IoT platform. It is necessary to complete the authentication and login of personal account, complete the creation of parameters, and fill in the protocol type and data format. Here, COAP/LWM2M is used as the application layer protocol and UDP is used as the transport layer protocol. Module communication program flow is shown in figure 9.

4.1.3 Low power programming of modules

The NB module itself has the characteristics of low power consumption, and the M5310-A module used in this design supports the RAI power-saving technology mode. RAI mode is implanted in the process of program design. This mode can greatly reduce the device waiting time, shorten the terminal connection state time from 20 seconds to less than 5 seconds, and reduce the power consumption of data reporting. However, the response of the upper computer will affect the effect of RAI, so the ACK response mechanism of IoT platform is used to decouple the device and the upper computer in connection.

The reboot program of the message module has also been changed to reduce unnecessary resends, limit the number of resends, reduce meaningless restarts and avoid packet loss. The specific changes are:
a. Waiting time for IOT platform ACK changed from 20s to 55s.
b. If sending twice in a row is unsuccessful, give up sending again and wait for the next event.
c. The module will be restarted only after a total of 8 unsuccessful remessages.

4.2 Upper computer software design
This paper is based on VS (Microsoft Visual Studio) PC design. The data transmission from Huawei IoT platform to the upper computer adopts HTTP protocol. The design of the upper computer realizes the real-time monitoring of the collected smoke data information, real-time understanding of the working state of the module and the remaining power of the module, etc[8].

4.3 Photovoltaic maximum power tracking algorithm
There are many types of MPPT algorithm, common persistence pressure tracking observation method, the incremental conductance method[9] and interference method, etc, combined with the application environment and hardware function, selecting variable step length conductance increment method as the photovoltaic maximum power point tracking control algorithm[10], incremental conductance method of maximum power point tracking control precision, response speed is faster, the incremental conductance method needs more precision sensors and the capability of floating point calculation of processor, the system can be satisfied. The core of MPPT incremental conductance method is to control \( \frac{dP}{dV} = 0 \).

\[
P = V \times I
\]

\[
\frac{dP}{dV} = \frac{d(VI)}{dV} = I + V \frac{dI}{dV} \approx V \left( \frac{I}{V} + \frac{dI}{dV} \right)
\]

The conductance and value-added conductance are:

\[
\frac{1}{V} \times \frac{dP}{dV} = \frac{I}{V} + \frac{dI}{dV}
\]

The update rule of the above reference working voltage \( V_{\text{ref}} \) can be expressed as:

\[
V_{\text{ref}} = V_{\text{ref}} + V_{\text{step}}
\]

Among them:

\[
V_{\text{step}} = \left\{ \alpha V \left( \frac{I}{V} + \frac{dI}{dV} \right) \over \beta \cdot \Delta I \right\}
\]

In the formula, \( \alpha \) and \( \beta \) are the accumulation factors, which to a certain extent determine the accuracy and dynamic response speed of the control algorithm. In order to ensure a better MPPT effect, it is very important to automatically adjust \( \alpha \). The value of \( \alpha \) is simply defined as follows:

\[
\alpha \leq \frac{V_{\text{step max}}}{{\left| \frac{dP}{dV} \right|}_{\text{max}}}
\]

\( V_{\text{step max}} \) is the maximum permissible update step size that is allowed in the case of fixed step size. The calculation flow chart of PV variable step size conductance increment method is shown in figure 10. \( \varepsilon_1, \varepsilon_2, \varepsilon_3 \) are all positive numbers close to zero.
5. System feasibility verification
The system innovates and designs the power supply mode of the narrow-band IoT [11], so whether the power supply can fully supply the equipment is the primary consideration. Through Matlab simulation, the charging and discharging current, voltage, and energy storage of the ultracapacitor group during the operation of the terminal equipment under the timely environment (room temperature 20℃, illumination 800W/m²) are shown in figure 11.

As for the output of the power system, the simulation of the voltage and current that can be output within 1S is shown in figure 12.
In terms of terminal power consumption, in a typical setting, it is detected once every 5s, and immediately sleeps after 10ms of each detection. The total all-day detection work is 172.8s, and the current during the detection work is 4.5mA. The simulation waveform of energy consumption is obtained, as shown in figure 13.

According to the energy consumption waveform, the estimation of system power consumption is shown in chart 1.

| Power consumption (mA) | Time(s) | Total power(mAs) |
|------------------------|---------|-----------------|
| Dormancy               | 0.0075  | 86400           | 648          |
| Detection              | 4       | 172.8           | 691.2        |
| Average                | 19      | 475             | 9025         |
| Daily total power      |         |                 | 10364.2      |
The simulation results show that the power supply design can meet the power consumption requirements of the device terminal and maintain the normal operation of the system as a whole. Under the premise of no failure of the device terminal and power supply, the device can theoretically maintain a long time working state without replacing the power supply and other equipment.

6. Conclusion
The system integrates solar power supply, supercapacitor energy storage and narrowband Internet of Things communication technology to get a brand new smoke sensing terminal, which realizes the self-power supply of the system. MCU transplants Ucos operating system to arrange and schedule indoor smoke data collection, terminal communication, energy storage and power supply, etc., to ensure the real-time performance of multi-task work. The system adopts solar maximum power point tracking to improve the utilization of solar energy. The selected hardware MUC, NB module and system circuit design are all featured with low power consumption. Under the premise of satisfying the normal operation of the terminal, the low power consumption of the system software program is optimized. It can be seen from the simulation results that the overall design of the circuit meets the requirements, the program algorithm is reasonable and reliable, and the terminal can work normally. It solves the persistent power supply problem of the smoke sensing terminal based on the narrowband Internet of Things, and it also has the advantages of environmental protection, energy saving and easy maintenance.

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Reference
[1] Yang Y, Zhang J. Research on Fire Alarm System of College Dormitory Based on Wireless Sensor Network [J]. Sensor World, 2013,19 (05):25-28, 40.
[2] LI Q. Absorption situation and development prospect of grid-connected photovoltaic power generation[J]. Electrotechnical Application, 2018, 37(16): 4-6.
[3] Zhang L , Wu G, Zhou H , et al. Design of Self—powered Fire Monitoring System Based on NB—IOT [J]. Radio Communications Technology, 2018, 44(5):0506—0511.
[4] Ren Z, Zhang G, Lin D et al. A review of wireless sensor network applications [J]. Transducer and Microsystem,2018,37(03):1-2.
[5] Wang X, Ouyang J, Ji A. Design of Solar Power Supply System with Wireless Sensor Network Nodes [J]. Microcontroller and Embedded System Applications, 2012,12 (3):56-58, 61.
[6] Liu W. Energy Storage of Supercapacitor in Independent Photovoltaic System [D]. Nanjing: Southeast University, 2010.
[7] Li Y. Research on Super Capacitor Energy Storage System [D]. Beijing: Beijing Jiaotong University, 2015.
[8] Li Q, Wang G, Zhu L. Mass Environmental Monitoring Data Storage and Sharing Platform [J]. Automation Instrumentation, 2016,37(2):61-64.

[9] Xu F, Yang Y. Research on equalization system for supercapacitor stacks based on switch matrix[J]. Telecom Power Technology, 2017, 34(3): 50-52.

[10]Yu G J, Jung Y S, Choi Y, et al. A novel two-Mede MPPT control algorithm based on comparative study of existing algorithms[J]. Conference Record of the 29th IEEE Photovoltaic Specialists Conference,2002:1531-1535.

[11]Zhou C, Jia W, Si Y et al. Design of Adjustable Optical Drive Power Supply for Solar Street Lamp Based on PWM [J]. Modern Electronic Technology,2019,(20).