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Design and Application of Community Intelligent Street Light Control System

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Abstract: *With the acceleration of urbanization, the intelligent management of community lighting facilities has become an important way to improve the quality of community living and energy utilization efficiency. Aiming at the problems existing in the community lighting system, this paper designs an intelligent street light control system based on STM32 microcontroller and NB-IoT communication technology. The system collects ambient light intensity and pedestrian information through light sensors and human infrared sensors to realize automatic dimming and remote monitoring functions of street lights, effectively reducing energy consumption and improving management efficiency. The experimental results show that the system can operate stably under different environmental conditions, the light intensity and street light brightness adjustment have a good linear relationship, the fault detection accuracy is high, and it has good application prospects and promotion value.*

Keywords: *Community Smart Street Lights; STM32; NB-Iot; Light Sensor; Human Infrared Sensor*

1. Introduction

As the basic unit of a city, the intelligent management of community lighting facilities is of great significance to improving the overall image of the city and the quality of life of residents. Traditional community street light control systems usually use timing or photosensitive control, which lacks flexibility and intelligence, and cannot effectively respond to complex and changing environmental conditions and actual needs[1].

This study aims to design an intelligent street lamp control system. By introducing advanced sensor technology, microcontroller technology and wireless communication technology, it can realize the automatic dimming, remote monitoring and fault detection functions of street lamps, improve energy utilization efficiency, reduce operation and maintenance costs, and enhance the intelligence level of community lighting management[2].

2. Overall system design

2.1 Functional Requirements Analysis

Automatic dimming function: This function is designed to automatically adjust the brightness of street lights according to the ambient light intensity to achieve energy-saving control. The system monitors the ambient light intensity in real time through the light sensor and transmits the data to the microcontroller. The microcontroller automatically adjusts the brightness of the street lights according to the preset dimming algorithm. For example, when the light is weak, such as at dusk or on cloudy days, the street lights automatically brighten; when the light is strong, the street lights automatically dim, thereby effectively reducing energy consumption[3].

Remote monitoring function: With the help of wireless communication technology, managers can remotely switch street lights in the monitoring center and monitor their operating status in real time. The system establishes a connection with the monitoring center through the NB-IoT communication module to achieve data transmission. Managers can send control instructions, which are transmitted to the microcontroller through the communication module to control the switch of street lights; at the same time, the status information of street lights can also be uploaded to the monitoring center in real

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time, so that managers can understand the operation status of street lights in a timely manner.

Fault detection function: The system can detect the operating status of street lamps in real time and give an alarm in time if a fault is found. The microcontroller collects the current and voltage data of the street lamps through current and voltage sensors. When the data exceeds the normal range, it is judged that the street lamp may be faulty. At this time, the system immediately sends an alarm message to the monitoring center through the communication module, prompting the management personnel to repair in time to ensure the normal operation of the street lamps[4-5].

Data collection and transmission function: The system needs to collect data such as light intensity, current, voltage, etc., and upload them to the monitoring center through the wireless communication module. The light sensor and current and voltage sensor collect the ambient light intensity and the street lamp working current and voltage data respectively. After being processed by the microcontroller, these data are transmitted to the monitoring center through the NB-IoT communication module. Based on these data, managers can analyze the operation status and energy consumption of street lamps, providing a basis for system optimization and management[6].

2.2 System architecture design

This system adopts a layered architecture design, including the perception layer, network layer and application layer. Each layer works together to ensure the efficient and stable operation of the system. Figure 1 System architecture.

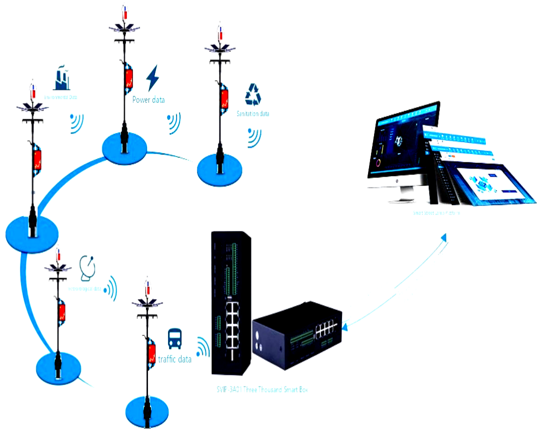

Figure 1 System architecture

Perception layer: As the basic part of the system, it consists of light sensors, human infrared sensors, current and voltage sensors, and street light controllers, responsible for collecting environmental information and controlling street lights. The light sensor monitors the ambient light intensity in real time to provide a basis for automatic dimming; the human infrared sensor detects human activities to achieve intelligent control of lights turning on when people come and turning off when people leave; the current and voltage sensors collect current and voltage data when street lights are working for fault detection; the street light controller adjusts the brightness or switches the street lights according to the instructions of the microcontroller[7].

Network layer: NB-IoT communication technology is used to achieve data transmission between the perception layer and the application layer. NB-IoT has the advantages of wide coverage, stable connection, and low power consumption, which can ensure reliable data transmission in complex environments. The data collected by the perception layer is sent to the monitoring center through the NB-IoT module, and the control instructions of the monitoring center are received at the same time to achieve remote management.

Application layer: Build a monitoring center platform to achieve remote management and data analysis of street lamps. The monitoring center is equipped with computers, servers and other equipment, and installed with special management software. Managers can intuitively monitor the operating status of each set of street lamps through the software interface, send control instructions, and analyze the collected data, such as generating energy consumption reports and analyzing fault causes, so as to optimize system management[8-9].

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2.3 Hardware selection

Microcontroller: STM32F103C8T6 is selected as the core controller of the system. It is based on the ARM Cortex-M3 core and has high performance, low power consumption and rich peripheral interfaces. Its high performance can meet the system's requirements for data acquisition, processing and control; its low power consumption is suitable for long-term stable operation in a community environment; and its rich peripheral interfaces such as I2C and UART are convenient for connecting light sensors, communication modules and other devices to achieve system function integration[10].

Light sensor: BH1750 digital light sensor is used, with a measurement range of 0-65535lx, high accuracy and simple interface. The sensor communicates with the microcontroller through the I2C interface, can accurately measure the ambient light intensity, and provide reliable data support for the automatic dimming function.

Human infrared sensor: The HC-SR501 pyroelectric infrared sensor is used to detect human activities, and the light turns on when people come and turns off when people leave. It has the advantages of wide detection range and adjustable sensitivity, which can effectively sense human movement and improve the intelligence level of the system.

NB-IoT communication module: The BC28 module has the advantages of wide coverage, stable connection, and low power consumption, and is suitable for remote control of large-scale street lamps. The module supports the NB-IoT network, which can realize wireless transmission of data and ensure smooth communication between the system and the monitoring center.

Street lamp driving circuit: Use PWM dimming to control the brightness of LED street lamps. By changing the duty cycle of the PWM signal, the LED current is adjusted to achieve brightness adjustment. PWM dimming has the advantages of simple control, low cost, and good dimming effect, which can meet the system's requirements for street lamp brightness adjustment.

2.4 Software Architecture Design

The software system is based on modular design concept and is divided into sensor data acquisition module, communication module, control module and data processing module. Each module cooperates with each other to realize the functions of the system.

Sensor data acquisition module: responsible for collecting data from light sensors, human infrared sensors, and current and voltage sensors. The light sensor data is read through the I2C interface, the human infrared sensor signal is obtained through the GPIO pin, and the current and voltage sensor data is collected through the ADC. After preliminary processing, these data are used by the control module.

Communication module: It realizes the interaction with the NB-IoT communication module and is responsible for sending and receiving data. It communicates with the BC28 module through the UART interface, packages the collected data and sends it to the monitoring center, and receives the control instructions from the monitoring center and passes them to the microcontroller.

Control module: The control module adjusts the brightness or switches the street light according to the collected data and control logic. The control module controls the street light drive circuit through the PWM signal based on the light intensity and the human infrared sensor signal to realize the functions of automatic dimming and turning on the light when people come and turning off the light when people leave. The control module also receives the control instructions from the communication module to perform remote switch operations.

Data processing module:The data processing module analyzes and processes the collected data, such as data filtering, unit conversion, etc., to improve data accuracy and reliability. The data processing module stores the processed data in the memory of the microcontroller for subsequent query and analysis. The data processing module also carries out data interaction between modules through well-defined interfaces to ensure the maintainability and scalability of the system software.

3. Hardware Circuit Design

3.1 STM32 controller circuit design

This system uses STM32F103C8T6 as the core controller, and designs its minimum system circuit

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to ensure stable operation, including clock, reset and power supply circuits. The clock circuit uses an 8MHz passive crystal oscillator with two 30pF capacitors to provide accurate clock signals for STM32; the reset circuit uses a combination of power-on reset and manual reset, using a 0.1μF capacitor and a 10kΩ resistor to form a power-on reset circuit, and then a reset button is connected in series to achieve system reset; the power supply circuit uses an AMS1117-3.3 voltage regulator chip to convert the external 5V power supply to 3.3V to power STM32 and sensors, and the power pin is connected in parallel with 0.1μF and 10μF capacitors to filter, effectively reducing power supply noise.

3.2 Light sensor circuit design

The light sensor selected is BH1750, which has a range of 0-65535lx, high accuracy and simple interface. It is connected to STM32 via the I2C interface to realize light intensity data collection. In the specific circuit design, the SDA and SCL pins of BH1750 are connected to the I2C1_SCL and I2C1_SDA pins of STM32 respectively. When wiring, appropriate pull-up resistors need to be connected in series, generally 4.7kΩ, to ensure stable signal transmission and meet the system's automatic dimming requirements for ambient light intensity.

3.3 Human infrared sensor circuit design

The human infrared sensor uses the HC-SR501 pyroelectric infrared sensor, whose output terminal OUT is connected to the PA0 pin of STM32 and configured as an external interrupt trigger mode. When human activity is detected, the HC-SR501 outputs a high-level signal to trigger the external interrupt of STM32, realizing the intelligent control function of turning on the light when people come and turning off the light when people leave. The VCC and GND pins of HC-SR501 are connected to the 3.3V power supply and GND respectively to ensure normal power supply.

3.4 NB-IoT communication module circuit design

The NB-IoT communication module uses BC28, designs its power supply, SIM card and antenna interface circuits, and connects to STM32 through UART to achieve wireless data transmission. In the power circuit, BC28 requires 3.3V-4.3V power supply, and selects 3.8V power supply through the voltage regulator circuit to ensure stable operation of the module; the SIM card interface circuit is designed according to the SIM card holder pin definition of BC28, and is connected to the SIM card holder pin of the module to achieve electrical connection of the SIM card; the antenna interface circuit selects an antenna with appropriate impedance matching and welds it to the antenna interface of BC28 to ensure good signal transmission. The UART_TXD and UART_RXD pins of BC28 are connected to the USART1_TX and USART1_RX pins of STM32 respectively to achieve data transmission and reception, so that the system has remote monitoring function.

3.5 Street light driving circuit design

The street lamp driving circuit adopts PWM dimming, and the brightness is adjusted by controlling the LED current through the MOS tube. In the specific design, the PWM signal is generated by the timer output pin of the STM32 and connected to the gate of the MOS tube to control the on-time and off-time ratio of the MOS tube, thereby adjusting the LED current and changing the brightness. The selection of MOS tubes needs to consider the current demand of LED street lamps, such as IRF540, which has a withstand voltage of 100V and a current capacity of up to 23A, which meets the general needs of LED street lamps. The positive pole of the LED street lamp is connected to the positive power supply, the negative pole is connected to the source of the MOS tube, and the drain of the MOS tube is grounded to form a current loop. When the duty cycle of the PWM signal changes, the LED current changes accordingly, realizing stepless brightness adjustment, achieving energy saving and intelligent control effects.

4. Software Design

4.1 Overall software process

After the system is powered on and initialized, the STM32 configures the parameters of each peripheral and then enters a cyclic working state. In the cycle, the light sensor and human infrared

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sensor data are collected regularly, the brightness of the street lamp is adjusted according to the control logic, and the data is uploaded to the monitoring center through the NB-IoT module, and the control instructions from the monitoring center are received at the same time. This design ensures that the system can respond to environmental changes and remote control commands in real time, realizing intelligent street lamp management.

4.2 Light sensor data reading and processing

```
#include "i2c.h"
#include "BH1750.h"
uint16_t BH1750_Read(void)
{
    uint8_t data[2];
    I2C_Start(); // Start I2C communication
    I2C_Send7bitAddress(BH1750_ADDR, I2C_Direction_Transmitter); // Send BH1750 device address and write mode
    I2C_SendByte(HBH1750_CMD); // Send command byte, set measurement mode
    I2C_Start(); // Restart I2C communication
    I2C_Send7bitAddress(BH1750_ADDR, I2C_Direction_Receiver); // Send BH1750 device address and read mode
    data[0] = I2C_ReceiveByte(); // Receive high byte data
    I2C_Ack(); // Send ACK signal
    data[1] = I2C_ReceiveByte(); // Receive low byte data
    I2C_NoAck(); // Send NACK signal
    I2C_Stop(); // Stop I2C communication
    return (data[0] << 8) data[1]; // Merge high and low bytes and return the light intensity value
}
```

This code implements the data reading of the BH1750 light sensor. It communicates with the sensor through the I2C interface, first sending a start signal and device address, and then sending a command byte to set the measurement mode. After that, it restarts the communication and switches to the read mode, receiving two bytes of light intensity data, and finally merging the data and returning it. In this way, the ambient light intensity information can be accurately obtained, providing data support for the subsequent automatic dimming function.

4.3 Human infrared sensor data processing

```
#include "stm32f10x.h"
void EXTI0_IRQHandler(void)
{
    if(EXTI_GetITStatus(EXTI_Line0) != RESET)
    {
        EXTI_ClearITPendingBit(EXTI_Line0); // Clear interrupt pending bit
        // Human infrared detects signal, processing logic
        // ...
    }
}
```

This code handles the interrupt signal of the human infrared sensor. When the interrupt is triggered, first check whether the interrupt status is valid, and then clear the interrupt pending bit to avoid repeated triggering. Next, you can add processing logic, such as adjusting the brightness of the street light or sending notifications. This can realize the intelligent control function of turning on the light when people come and turning off the light when people leave, improving the interactivity and energy saving effect of the system.

4.4 NB-IoT communication module design

```
#include "usart.h"
void BC28_SendData(uint8_t *data, uint16_t len)
{
    USART_SendData(USART1, data, len); // Send data via USART1
}
```

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```
void BC28_ReceiveData(void)
{
    // Receive data processing
    // ...
}
```

This code implements the data sending and receiving functions of the NB-IoT communication module. The `BC28_SendData` function sends data through USART1 and sends the data of the specified length from the buffer. The `BC28_ReceiveData` function is used to process the received data, and can add parsing and processing logic, such as updating the status of street lights or storing received information. In this way, the system can interact with the remote monitoring center to achieve remote monitoring and management functions.

4.5 Control actuator code

```
#include "pwm.h"

Void LED_SetBrightness(uint8_t brightness)

{

TIM_SetCompare1(TIM2, brightness); // Set the compare register 1 value of TIM2 timer to control PWM duty cycle

}
```

This code controls the brightness of the LED street light through a PWM signal. The `LED_SetBrightness` function accepts a brightness value as a parameter and sets it to the compare register 1 of the TIM2 timer, thereby changing the duty cycle of the PWM signal. The change in duty cycle directly affects the LED current, which in turn adjusts the brightness. This allows for smooth brightness adjustment to meet lighting needs under different ambient light intensities.

4.6 Data processing and decision making

```
#include "control_logic.h"
void ControlLogic(void)
{
    uint16_t light_intensity = BH1750_Read(); // Read light intensity
    uint8_t pir_status = GPIO_ReadInputDataBit(GPIOA, GPIO_Pin_0); // Read the status of the human infrared sensor

    if(pir_status == SET)
    {
        // Someone passes by, turn on the street light
        LED_SetBrightness(MAX_BRIGHTNESS); // Set the maximum brightness
    }
    else
    {
        // Adjust brightness according to light intensity
        uint8_t brightness = Map(light_intensity, 0, 65535, MIN_BRIGHTNESS, MAX_BRIGHTNESS); // Map light intensity to brightness range
        LED_SetBrightness(brightness); // Set the calculated brightness
    }

    // Upload data
    BC28_SendData((uint8_t *)&light_intensity, sizeof(light_intensity)); // Upload light intensity data
    BC28_SendData((uint8_t *)&pir_status, sizeof(pir_status)); // Upload the status of the human infrared sensor
}
```

This code implements the control logic of the system. First, read the light intensity and the status of the human infrared sensor. If a person is detected passing by, the street light is adjusted to the maximum brightness; otherwise, the appropriate brightness is calculated according to the light intensity

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and adjusted. The collected data is then uploaded to the monitoring center through the NB-IoT module. This ensures that the system can provide appropriate lighting in different environments and realize remote monitoring and data analysis functions.

5. Experimental testing and result analysis

5.1 Experimental environment and equipment

On a road in a community, we carefully selected 10 points to install a complete set of street light control systems. Each point is equipped with an STM32 controller, light sensor, human infrared sensor, NB-IoT communication module and LED street light. At the same time, we built a powerful monitoring center platform, which can not only receive and display the data sent back by the street light, but also send control instructions to achieve remote control of the street light. This road was chosen as the experimental site because it is representative and covers various scenes of community roads, such as straight roads, curves, ramps, etc., which can fully verify the performance and stability of the system.

5.2 Experimental content and methods

Experiment on the relationship between light intensity and street light brightness adjustment: We carefully selected multiple moments with different light intensities at different times of the day, used a professional light intensity meter to accurately measure the ambient light intensity, and recorded the corresponding street light brightness adjustment. In this way, we fully verified the system's automatic dimming function under different lighting conditions, ensuring that it can respond accurately to changes in ambient light intensity and achieve energy-saving control.

Experiment on the impact of human infrared sensors on street light brightness: In order to verify the function of human infrared sensors, we conducted multiple tests on this experimental road. When no one passes by, observe whether the brightness of the street light remains at the default brightness adjusted according to the light intensity; when someone passes by, record whether the brightness of the street light can be quickly adjusted to 100% to ensure sufficient lighting and provide convenience and safety for pedestrians. Through repeated field tests, we have fully verified the effectiveness of human infrared sensors in different scenarios.

Remote monitoring function test: With the help of the monitoring center platform, we sent a large number of switch light commands, covering different times, different street light combinations and other scenarios, and carefully checked the response of the street lights. We focused on whether the street lights could receive the commands in time and execute them accurately, ensuring the reliability of the remote monitoring function, so that managers can easily control the status of street lights away from the site.

Fault detection function test: In order to test the fault detection capability of the system, we artificially simulated a variety of street lamp fault conditions, such as short circuit, open circuit, bulb damage, etc. After simulating the fault, we closely observed whether the system could detect the fault within the specified time and issue an alarm message in a timely manner. In this way, we comprehensively evaluated the perfection of the system's fault detection function to ensure that it can detect and report problems in a timely manner in actual applications, reducing maintenance costs and repair time.

5.3 Experimental data recording and analysis

5.3.1 Experimental data on the relationship between light intensity and street light brightness adjustment

Tables1: Experimental data on the relationship between light intensity and street light

Lightintensity (lx)	Streetlight brightness (%)
0	100
10000	80
20000	60
30000	40
40000	20
50000	10
60000	5

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As shown in Table 1, as the light intensity increases, the street light brightness gradually decreases, showing a good linear relationship, indicating that the system's automatic dimming function is normal. For example, when the light intensity is 0lx, the street light brightness reaches 100%, providing sufficient lighting for nighttime or completely dark environments; when the light intensity increases to 60000lx, the street light brightness is only 5%, effectively avoiding energy waste and light pollution caused by excessive street lights in strong light environments.

5.3.2 Experimental data on the impact of human infrared sensors on street light brightness

Table 2: Experimental data on the impact of human infrared sensors on street light

Human body status	Street light brightness (%)
unmanned	50
Someone	100
unmanned	50

As shown in Table 2, when someone passes by, the street light brightness is quickly adjusted to 100%, and when no one is around, it returns to the brightness adjusted according to the light intensity, verifying the effectiveness of the human infrared sensor. This shows that the system can intelligently sense human activities, turning on the lights when people come and dimming the lights when people leave, which not only improves the safety and convenience of community residents' night travel, but also further saves energy.

5.3.3 Remote monitoring function test results

The switch command was sent through the monitoring center platform, and the street lights responded promptly, with a 100% switch success rate, indicating that the remote monitoring function is reliable. During the test, whether it is the control of a single street light or the operation of a batch of street lights, the system can execute the command quickly and accurately, greatly improving management efficiency and reducing the workload and time cost of manual inspections.

5.3.4 Fault detection function test results

After simulating a street lamp failure, the system issued an alarm message within 1 minute with an accuracy rate of 100%, indicating that the fault detection function is perfect. In the experiment, no matter what type of fault it is, the system can quickly detect and notify the management personnel in time, ensuring that the fault can be handled in time, reducing the impact on community lighting and improving the overall reliability of the system.

5.4 Experimental conclusion

The experimental results show that the community intelligent street light control system designed in this paper can operate stably, and all functions have achieved the expected results. There is a good linear relationship between the light intensity and the street light brightness adjustment. The human infrared sensor can effectively control the street light brightness. The remote monitoring and fault detection functions are reliable, and it has good application prospects. In practical applications, this system can not only effectively reduce energy consumption and improve energy utilization efficiency, but also improve the intelligent level of community lighting management, providing residents with a safer, more comfortable and convenient night environment. At the same time, the stability and reliability of the system have also been fully verified, laying a solid foundation for large-scale promotion and application.

6. Conclusion

This paper designs a community intelligent street light control system based on STM32 and NB-IoT,which realizes automatic dimming, remote monitoring and fault detection functions. Through hardware circuit design and software program writing, a complete system is built, and experimental tests are carried out in an actual community environment. The results show that the system runs stably, has complete functions, can effectively reduce energy consumption and improve management efficiency.

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