Design and Implementation of Streetlights Based on Zigbee Wireless Technology

Zhiguo Zheng [1,2], Xueping Fu [1], Zirui Li [1]

[1] School of Information Engineering, Hainan Vocational University of Science and Technology, 571126, Haikou, China

[2] School of Information and Communication Engineering, Hainan University, 570228, Haikou, China

Abstract: Streetlights, as an essential component of public infrastructure in urban areas, play a critical role in modern cities. Considering the current state of street lighting systems in China, this paper proposes an intelligent streetlight system based on Zigbee wireless communication technology. The article begins by introducing and analyzing the research background and significance of intelligent streetlights. Following this, a comprehensive design scheme is proposed based on functional requirements. By analyzing the characteristics of Zigbee wireless communication technology, an appropriate solution is selected to meet the functional requirements of the intelligent streetlight system, and the specific implementation process is detailed. Furthermore, the hardware and software design of the intelligent streetlight system is thoroughly explained according to practical needs. Finally, the functionality of the intelligent streetlight system is tested, and results demonstrate that it successfully achieves the intended functions.

Keywords: Streetlight; Zigbee; Wireless Communication; Software Design; Testing

1. Introduction

Streetlights are one of the indispensable components of urban infrastructure and can even directly reflect the level of a city's development. In recent years, with the continuous advancement of smart lighting technology, intelligent streetlights have gradually appeared on the streets and alleys of cities. Since the beginning of the 21st century, scientific and technological progress has driven significant transformations in the field of public lighting. These advancements have enabled the deployment and use of intelligent streetlights in various parts of urban areas.

Compared to the advantages of intelligent streetlights, traditional streetlights, despite their attractive appearance, have many hidden drawbacks. With the changing seasons, the length of day and night varies—longer days and shorter nights in summer result in reduced evening streetlight usage, while shorter days and longer nights in winter lead to increased usage. Intelligent streetlights can adapt to environmental changes and adjust lighting accordingly, enabling efficient and rational control of lighting periods.

2. Related Work

2.1 ZigBee Technology

ZigBee wireless communication technology is a rapidly developing low-complexity, low-power, low-cost, short-range wireless bidirectional communication technology based on the IEEE 802.15.4 standard for low-rate wireless personal area networks (LR-WPANs). It is typically used for data transmission between short-distance electronic devices [1]. Due to its low-power consumption advantage, ZigBee technology is widely applied in areas requiring low-latency data transmission and cyclic data communication. Additionally, ZigBee supports periodic and intermittent data transmission, making it extensively utilized in fields such as smart homes, small electronic devices, and sensor networks.

2.2 IAR Development Tool

IAR Embedded Workbench is a development environment created by the Swedish company IAR Systems for microprocessor integration, supporting platforms including ARM-based chips. The IAR system provides a complete toolchain, including an integrated development environment and code analysis tools [2], playing a significant role in embedded development. In this study, the design utilizes the IAR Embedded Workbench development environment and is based on TI's Z-Stack CC2530-2.3.1-1.40 protocol stack to develop the required program code.

2.3 Software Development Language

The software code in this study is written in C language, which provides a wide range of functions, including system-generated functions and user-defined functions [3]. Additionally, C language allows the creation of functional modules that can be programmed or defined according to specific requirements. Furthermore, C is a structured programming language, and its modular structure makes debugging, testing, and maintaining the program significantly easier.

3. System Principle and Components

3.1 System Principle

The intelligent streetlight design in this project consists of a CC2530F256 core board (including a serial port section and buttons), a SmartRF04EB emulator, two LED indicator lights, a sensitive photoresistor sensor, and an active buzzer, among other components. The system uses ZigBee wireless communication to transmit data to the terminal node, achieving control over the streetlight's on/off state.

The serial port circuit of the CC2530F256 core board primarily uses the MAX3232 chip. This chip supports an input voltage of either 3.3V or 5V and performs the key function of converting TTL levels to RS-232 levels. The module is powered by a DC power supply, and the power module uses the MIC29302 chip, which converts 5V DC voltage into 3.3V DC voltage to provide power for the CC2530 module. The CC2530 chip serves as the core processing chip for establishing and managing the ZigBee network, making it a critical component of the system.

The design configures the CC2530F256 microcontroller pins as follows: the P10 port pin is assigned to control the LED module via the photoresistor sensor, the P11 port pin is designated for controlling the LED module via a button, the P07 port pin is used for the button-controlled buzzer alarm module, and the P06 port pin is allocated for the photoresistor sensor control module. The software design for this project utilizes the IAR Embedded Workbench development environment to write the required program code.

3.2 Hareward Components

The system includes the following hardware modules:

1. CC2530

The CC2530 (a wireless system-on-chip microcontroller) enables the creation of robust networks with multiple network nodes at a very low hardware cost. It is available in flash memory configurations of F32, F64, F128, and F256, with this study selecting the F256 configuration [4]. The practicality and advantages of the CC2530 processor include the full integration of a highly efficient RF transceiver, a standard 8051 microcontroller, 8KB of RAM, and the capability for additional functional extensions, along with strong support for external peripherals (see Figure 1).

The CC2530F256 chip supports all IEEE 802.15.4-based standards, including ZigBee, ZigBee Pro, and ZigBee RF4CE solutions. Furthermore, the chip enhances receiver sensitivity and provides programmable output power in receive, transmit, and various low-power modes, resulting in extremely low energy consumption during operation. The CC2530 offers different operating modes tailored for systems requiring ultra-low power consumption, making it well-suited to systems with strict energy efficiency requirements. Its operation features quick transitions between modes, ensuring extended battery life. This characteristic aligns perfectly with the core energy-saving concept of this project, providing strong feasibility support for reducing energy usage.

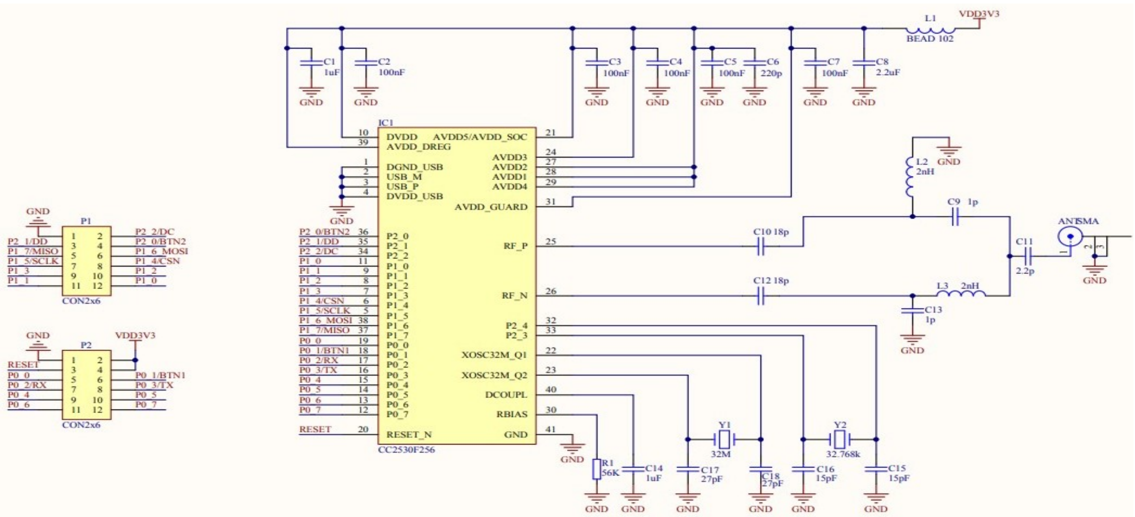

Figure 1: CC2530 Architecture.

2. Power Module Circuit

The power supply system functions as a crucial module, providing energy for the intelligent streetlight. The CC2530's digital core and peripherals are powered by a 1.8-V low-dropout regulator, which includes a power management feature. This enables the chip to operate in various power supply modes, supporting low-power applications with extended battery life.

3. Photoresistor-Controlled LED Module

The photoresistor sensor is a sensitive device capable of responding to or converting external light radiation or light signal changes. It is also one of the most widely used and highly produced sensors [5] (as shown in Figure 2). Photoresistor sensors play a critical role in automation control and electrical measurement technology (non-electrical quantities). Among these sensors, the simplest electronic component is the photoresistor, which detects variations in light intensity by sensing the brightness or dimness of the light (specific parameters are shown in Table 1).

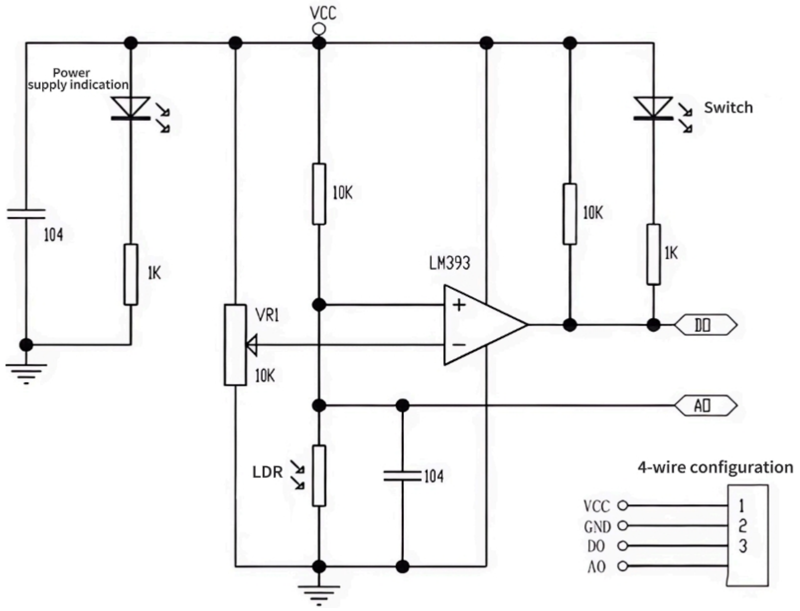

Figure 2: Circuit Diagram of the Photoresistor.

The photoresistor sensor module used in this study is a 4-wire module with four pins: Do, Ao, VCC, and GND. The connections are as follows:

1) VCC: Connects to the positive power supply (3.3V or 5V).
2) GND: Connects to the negative power supply (GND).
3) Do: TTL switch signal output port.
4) Ao: Analog signal output port.

The CC2530F256 microcontroller is designed with the P06 pin as the control pin for the photoresistor sensor. Using Dupont wires, the connections are established as follows:

1) The photoresistor sensor's VCC is connected to the 5V power supply of the CC2530F256.
2) The photoresistor sensor's GND is connected to the GND pin of the CC2530F256.
3) The photoresistor sensor's Do is connected to the P06 pin of the CC2530F256.

Table 1: Photoresistor Product Parameter Details.

Driver	Exceeds 15mA
Operating Voltage	3.3 V—5 V
Size of PCB	3.2 cm × 1.4 cm
Output Format	Do: Digital Switch Output (0/1) Ao: Analog Voltage Output
Comparator	Wide Voltage LM393 Comparator
Model	Sensitive Photoresistor Sensor
Wiring Type	4-Wire

4. Buzzer

The buzzer (see Figure 3) is an integrated electronic sounder that operates on a DC power supply. It converts electrical signals into sound signals and is widely used as an electronic component for key tones, alarm sounds, and other prompt signals. Buzzers are commonly applied in devices such as computers, alarms, automotive electronics, timers, and other electronic products as sound-generating components.

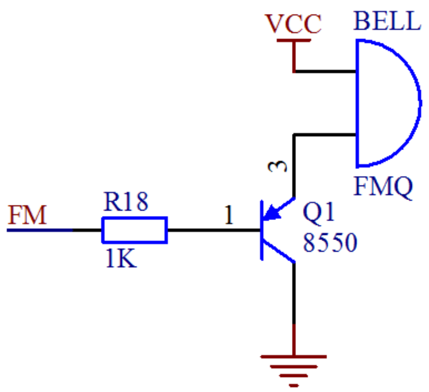

Figure 3: Structure Diagram of the Buzzer.

5. Button Control Module Design

The buzzer module used in this study is a 3-wire active buzzer module, which has three pins: VCC, I/O, and GND.

The design configures the P07 pin of the CC2530F256 microcontroller as the control pin for the buzzer. Using Dupont wires, the connections are established as follows:

1) Connect the buzzer's VCC pin to the 3.3V power supply of the CC2530F256.

2) Connect the buzzer's I/O pin to the P07 pin of the CC2530F256.

3) Connect the buzzer's GND pin to the GND pin of the CC2530F256.

3.3 System Software Composition

1. IAR EW System Development Tool

IAR Embedded Workbench, developed by the Swedish company IAR Systems, is a development environment designed for microprocessor integration. It supports platforms with various cores, including ARM-based chips. IAR Systems provides a comprehensive toolchain, which includes an integrated development environment and code analysis tools.

Leveraging IAR Systems' long-standing and extensive partnerships, the IAR development environment now supports over 7,000 chip products. Its highly optimized compiler is capable of generating extremely fast target code while minimizing power consumption.

Therefore, the software design for the intelligent streetlight system in this project uses the IAR Embedded Workbench as the development environment. The required program code is written based on the TI-provided Z-Stack CC2530-2.3.1-1.40 protocol stack.

2. Specific Program Design

Alarm Module:

1) Set the IO port for the button.

- Function Name: '`KEY_Init()`'
- The relevant design code is as follows:

```
void KEY_Init(void)
{
    P0IEN |= 0x02;
    PICTL |= 0x01;
    IEN1  |= 0x20;
    P0IFG  = 0x00;
    EA     = 1;
}
```

2) Configure the IO Port for the Buzzer

- Function Name: BEEP_Init
- Set the P0_7 port to output mode and general IO.
- The relevant design code is as follows:

```
void BEEP_Init(void)
{
    P0DIR |= 0x80;
    P0SEL &= ~0x80;
    BEEP = BEEP_OFF;
}
```

3) Configure the Interrupt Service Function：

- Function Name: ‘`P01_ISR`’
- Interrupt service function for P0_1.
- The relevant design code is as follows:

```
#pragma vector = P0INT_VECTOR
interrupt void P01_ISR (void)
{
    DelayMS(10);
    if(KEY == 0)
    {
        beep_flag = (beep_flag==BEEP_ON BEEP_OFF:BEEP_ON);
        led2_flag = (beep_flag==BEEP_ON BEEP_OFF:BEEP_ON);
    }
    P0IFG = 0x00;
    P0IF = 0x00;
}
```

4 Result Testing

4.1 Software Program Testing

Using the IAR Embedded Workbench development environment, the mq2 file was created and tested. The test results (see Figure 4) were successful, and the program ran as expected.

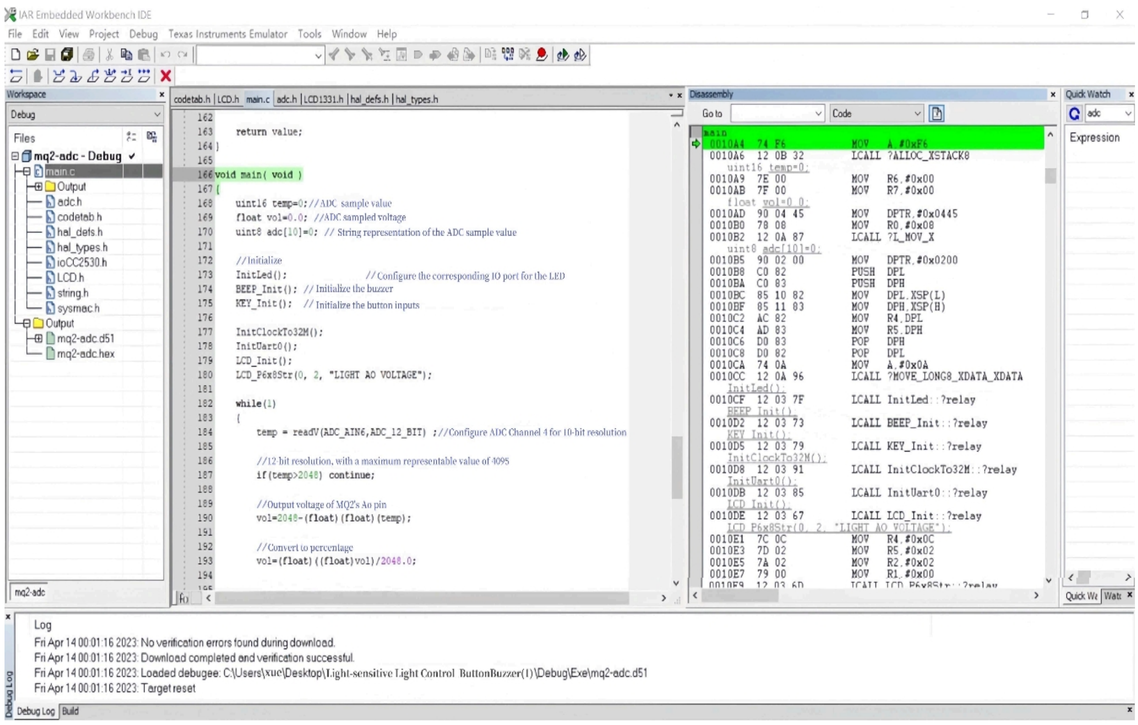

Figure 4: Software Execution Results.

4.2 Hardware Function Testing

1. Photoresistor Testing

After successfully writing the program code to the CC2530F256 and running it, the photoresistor sensor functioned as expected. It was able to detect changes in light intensity and, based on the designed light intensity threshold (when the light intensity is greater than 80), controlled the Do pin to turn the LED on or off (as shown Figure 5).

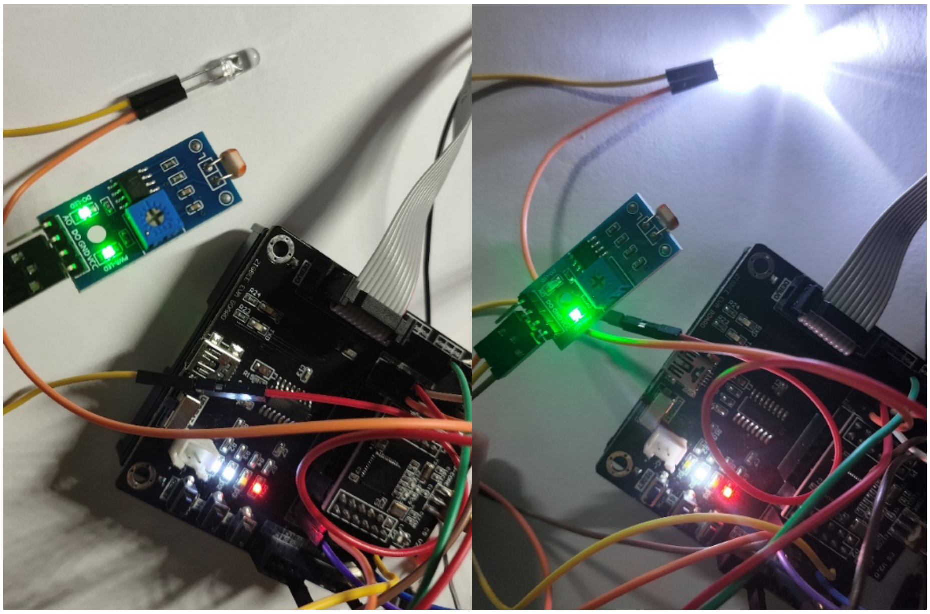

Figure 5: Photoresistor Testing.

2. Button LED Testing

As show in Figure 6, The LED2 indicator light is designed as the response light for the button-controlled LED module. Its positive terminal is connected to P11 of the CC2530F256, and its negative terminal is connected to the GND of the CC2530F256. Test results show that when the S1 button is pressed, the LED2 light remains on. Pressing the button again turns off the LED2 light, which aligns with the expected behavior.

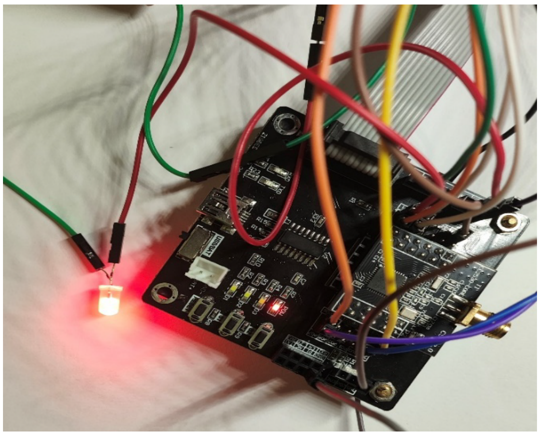

Figure 6: Button LED Testing.

5. Discussion

Modern society is continuously improving across various regions and levels, reflecting the growing advancement of urban civilization. As people's material living standards steadily improve, the development of spiritual and cultural advancements has also seen significant progress. Modern urban lighting construction stands as one of the most iconic symbols of civilization. It not only fulfills its fundamental function of illumination but also plays a crucial role in enhancing the urban aesthetic environment. Therefore, the goal of advancing intelligence in urban lighting is not only to meet the essential requirements of illumination but also to provide people with a higher level of aesthetic and cultural experience. This contributes significantly to the sustainable development of modern cities.

With the continuous advancement of scientific and technological research, intelligence and human-centric design have become higher standards in urban development. Increasingly, computer technologies, network communication systems, and intelligent sensor technologies are being integrated into smart lighting systems. These advancements form the essential technological foundations for the design and implementation of intelligent streetlights.

The primary significance of the intelligent streetlight system designed in this study is its ability to adapt to real-time environmental changes and intelligently assess needs. This ensures better functionality in areas such as illumination and public security, fulfilling its intended purpose effectively.

Intelligent streetlights based on Zigbee wireless communication technology will continue to improve in future practical applications and achieve significant results in urban development. In the process of increasingly advanced modern civilization, intelligent streetlights, with their unique intelligent features, have significantly alleviated real-world issues such as energy waste.

Although challenges remain in terms of widespread implementation, construction, and certain technical shortcomings, ongoing advancements in wireless communication technology will enable intelligent streetlights to develop more application functionalities and refine their solutions. These efforts aim to achieve greater social value and contribute to sustainable urban development.

References

[1] Chen X. (2021). The intelligent street light control system for preventing heavy fog of expressway based on zigbee. Wireless Personal Communications, 121(1):353-359.

[2] Chen X. (2024). Research on Intelligent Street Light Control System for Anti fog on Freeway Based on Wireless Network.

[3] Kadirova S, Nenov T, Kajtsanov D. (2020, October). IoT based automatic electronic system for monitoring and control of street lighting. In 2020 IEEE 26th International Symposium for Design and Technology in Electronic Packaging (SIITME) (pp. 122-126). IEEE.

[4] Gao F, Jin H. (2021). Design of ZigBee-Based Control System of Urban Intelligent Street Light. In Emerging Trends in Intelligent and Interactive Systems and Applications: Proceedings of the 5th International Conference on Intelligent, Interactive Systems and Applications (IISA2020) (pp. 672-679). Springer International Publishing.

[5] Tleubayeva A, Maidanov A, Kantayeva A. (2022). A model of an autonomous smart lighting system using sensors. Scientific Journal of Astana IT University, 34-44.