

Design and Implementation of Intelligent Traffic Signal Control System Integrating Temperature, Humidity and Light Sensing Monitoring

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Abstract:

With the continuous development of urban traffic and the improvement of intelligence levels, the intelligent design of traffic signal light systems has become one of the current research hotspots. This paper aims to design and implement an efficient traffic signal light control system to enhance traffic efficiency and reduce the incidence of traffic accidents. Firstly, the STM32F103C8T6 is adopted as the main control chip. Secondly, the DHT11 temperature and humidity sensor and the photosensitive sensor are used to detect the climate conditions at intersections in real time. The accident mode reminder and countdown functions are also included. Finally, the information is displayed through the OLED screen. This paper uses the research methods of hardware design, software design, and experimental verification. The key technologies of this paper include the application of STM32 microcontrollers, the hardware and software design of traffic signal light control systems, and performance evaluation. These studies not only help to improve urban traffic efficiency but also provide practical solutions for the development of intelligent transportation systems.

Keywords:

STM32F103C8T6, Temperature and Humidity Sensor, Microcontroller, Control System, DHT11

1. Introduction

The system design of this paper focuses on solving the practical problems in urban traffic management [1]. In response to the increasingly serious traffic congestion phenomenon, we aim to improve the utilization efficiency of road resources through intelligent control means and ensure the safe passage of pedestrians and vehicles.

The system structure mainly includes two major parts: hardware and software. In terms of hardware, we have selected the high-performance STM32F103C8T6 single-chip microcomputer as the main control chip. With its low power consumption, low voltage, high processing capacity, and rich peripheral resources and communication

interfaces, it is widely used in various embedded systems [2]. (According to the data from the STM official website,) The STM32F103C8T6 has a main frequency of up to 72MHz and a rich set of GPIO pins. The system also includes a temperature and humidity sensor DHT11 for temperature and humidity detection [3], and a photosensitive sensor that senses changes in light in real time to ensure that the display module of the OLED screen matches the environmental conditions.

In terms of software design, programs are written in C language to implement the timed switching logic of red, green and yellow lights, the display of temperature, humidity and light intensity values, and the reminder function of accident modes [4]. Strict system debugging and optimization are carried out to ensure the accuracy and response speed of signal light control. Throughout the entire design process [5], we fully considered the scalability and maintainability of the system to facilitate flexible upgrades and maintenance in the future development of urban transportation. Through a scientific testing plan, a comprehensive assessment of the system's performance is conducted to verify its effectiveness and stability in practical applications, providing strong technical support for optimizing the urban traffic environment [6].

2. Hardware Design of Traffic Signal Light Control System

2.1. Selection and Performance Indicators of Single-chip Microcomputers

In the design process of the traffic signal light control system, the selection of the single-chip microcomputer is a crucial step. The basis for choosing the STM32F103C8T6 single-chip microcomputer model mainly stems from the following key performance indicators:

The STM32F103C8T6 is a 32-bit flash memory microcontroller based on the ARMCortex-M3 core, with a main frequency processing speed of up to 72MHz, which can meet the real-time and high efficiency requirements of complex traffic signal logical operations [7]. It adopts the LQFP48 package. It also features abundant peripheral resources and GPIO interfaces, facilitating seamless connection with various sensors and actuators to ensure the precise execution of signal light control. This single-chip microcomputer is supported by powerful peripheral devices, such as ADC and PWM (Pulse Width modulation is a method of digitally programming the level of analog signals). The module can precisely read and respond to environmental variables, such as the data from the DHT11 temperature and humidity sensor, achieving intelligent environmental adaptability. The pin arrangement is shown in Figure 1.

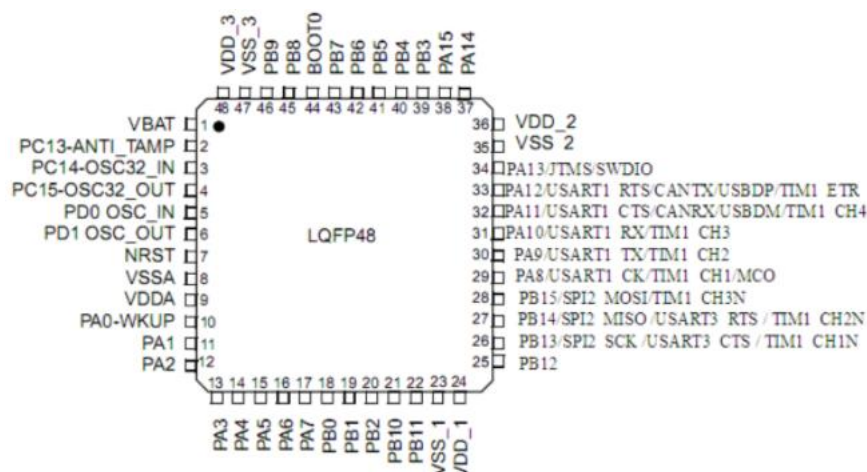


Figure 1. Pin arrangement of STM32F103C8T6.

The STM32F103C8T6 features low power consumption application requirements, with a temperature range of -40°C to $+85^{\circ}\text{C}$ and a supply voltage of 2.0V to 3.6V [8]. For traffic signal light control systems, this means maintaining stable performance over long-term operation and under various climatic conditions, reducing energy consumption, and conforming to the green and energy-saving design concept. In terms of memory, the program memory capacity is 64KB and the RAM capacity is 20KB [9], providing sufficient space for the storage of signal light control algorithms and real-time data processing. Its powerful debugging tool support also makes the development process more convenient.

Taking all the above factors into account, STM32F103C8T6, with its outstanding performance and wide compatibility [10], has become the fundamental platform for us to build efficient and reliable traffic signal light control systems.

2.2. Temperature and humidity sensor and photosensitive sensor selection

In the part of hardware circuit design, we focus on building a fully functional and reliable traffic signal light control system.

To achieve environmental perception, the DHT11 temperature and humidity sensor as shown in Figure 2 is used. It is equipped with internal temperature and humidity sensing elements, including a resistive humidity sensing element and an NTC temperature measurement element, and is connected to a high-performance 8-bit single-chip microcomputer [11]. It has an internal AD conversion function and adopts a single bus. Data exchange and control in the system are all completed by a single bus [12]. It features low cost, long-term stability, measurement of relative humidity and temperature, excellent quality, ultra-fast response, strong anti-interference ability, extremely long signal transmission distance, digital signal output, and precise calibration. It can monitor the climatic conditions at intersections in real time and ensure that the display screen is adjusted in a timely manner according to environmental changes.



Figure 2. DHT11 temperature and humidity sensor.

Light intensity detection uses a photosensitive sensor and a wide-voltage LM393 comparator. The signal is clean, the waveform is good, and the driving capacity is strong. The photosensitive resistor model selected is: 5516, the analog AO can be connected to the AD module. Through AD analog-to-digital conversion, the obtained analog signal is converted into a digital signal. When the ambient light brightness does not reach the set threshold, the DO terminal outputs a high level. When the external ambient light brightness exceeds the set threshold, the DO terminal outputs a low level. The detection brightness can be adjusted through a potentiometer. Turning

the potentiometer clockwise increases the detection brightness. Turn the potentiometer counterclockwise and the detection brightness will decrease. Then, through calculation, the digital signal is converted into the light intensity value to ensure driving safety and smooth road flow.

The entire hardware circuit design adheres to the principles of low power consumption, high reliability and easy maintenance. All components are carefully selected and laid out to ensure the stable operation of the system. Through reasonable hardware configuration and meticulous wiring design, the PCB board was drawn. We constructed a traffic signal light control system that can not only meet the basic functional requirements but also adapt to various environmental conditions. Figure 3 shows the bottom and top layer diagrams of the PCB board we designed.

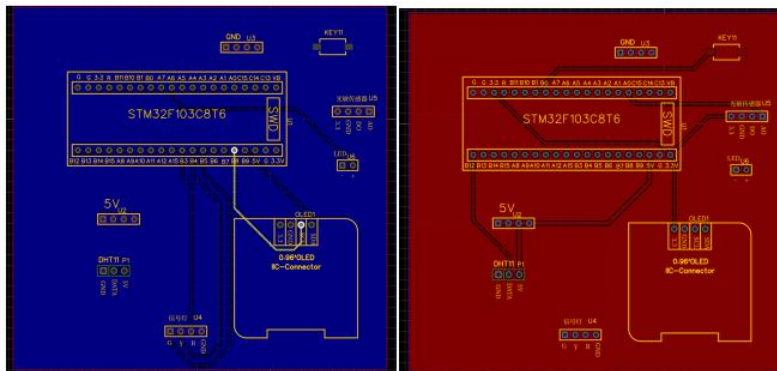


Figure 3. Bottom and top layer diagrams of the PCB board.

3. Software Design of the Control System

Figure 4 illustrates the entire software system architecture to achieve intelligent control of the single-chip microcomputer STM32F103C8T6 in the traffic signal light control system. We follow the principle of modular programming and divide the software into key modules, such as timer management, input and output processing, and user interface display. These modules work together to ensure that the switching logic of the signal lights is clear and the response is prompt.

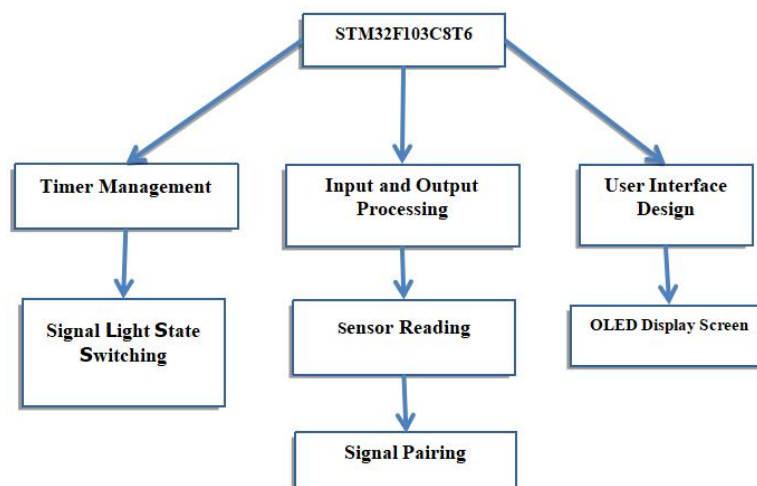


Figure 4. The overall software system architecture.

The timer management module is responsible for adjusting the state switching of signal lights according to the preset time cycle, such as the switching of green light, yellow light and red light. The input and output processing module integrates the

sensor reading function to monitor environmental variables (such as temperature and humidity) in real time and display the environmental conditions accordingly to remind pedestrians to pass.

User interface design is the key to enhancing user experience. OLED displays are adopted to clearly show the current environmental condition signal status and countdown information, which is convenient for drivers and pedestrians to understand. Write efficient low-level driver programs through C language to ensure seamless connection among all modules and accurate data exchange.

During the design process, we fully considered the scalability and maintainability of the software and reserved interfaces for possible new functions to be added in the future or for optimizing existing functions.

4. Effect Verification and Analysis

4.1. Verification of temperature and humidity monitoring function

The DHT11 temperature and humidity sensor can detect the temperature and humidity and display them on the OLED screen. In the summer in the north without rain, the air humidity is approximately 30%-50%. Through the OLED screen, the humidity can be seen as 44%. The temperature and humidity detection scenario is shown in Figure 5.

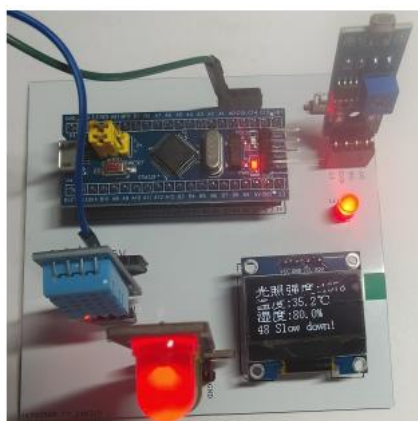


Figure 5. Schematic diagram of temperature and Humidity detection.

We can simulate the humidity during rain by breathing. When the air humidity reaches above 80%, the screen will show “SLOW Down!” The words can remind pedestrians and vehicle drivers to drive carefully and slowly to avoid traffic accidents. We can remind drivers not to drive for a long time when the temperature is too high by checking the temperature on the display screen.

4.2. Verification of light intensity monitoring function

Figure 6 shows the light intensity values. Appropriate light intensity can ensure driving safety and improve driving comfort. We can install light intensity display screens on main and secondary roads in cities respectively. For main roads in cities, due to the large volume of traffic and generally low vehicle speeds, the requirement for illuminance is relatively high. Secondary roads mainly connect the main urban roads and residential areas. The traffic volume is relatively small and the vehicle speed is also lower.



Figure 6. Physical picture of light intensity detection.

The transportation department should select appropriate lighting fixtures to provide a better lighting environment for driving. Improve the visibility of driving and reduce the possibility of accidents. We can use cardboard shielding to simulate the light intensity values under different lighting conditions.

4.3. Functional verification of traffic signal lights

The countdown module of the traffic light designed in this system is 20 seconds for the red light, 36 seconds for the green light, and 4 seconds for the yellow light to flash. Through multiple tests, it was found that the cycle period and switching of the traffic light are accurate and error-free. Figure 7 shows the status of the traffic light and the countdown display time.



Figure 7. Verification of Traffic Signal Light.

Based on the above test results, our traffic signal light control system has achieved the design goals in terms of performance. It not only effectively solves the problem of traffic congestion but also ensures the safety of pedestrians and vehicles, providing a reliable solution for urban traffic management.

5. Conclusions

This paper successfully designs and implements a set of intelligent traffic signal light control system based on STM32F103C8T6 single-chip microcomputer. The core innovation of the system lies in the integration of environmental perception capabilities. By integrating the DHT11 temperature and humidity sensor and the photoresistor sensor, it can monitor the changes in temperature, humidity and light

intensity at intersections in real time. The hardware design adheres to the principles of low power consumption, high reliability and easy maintenance, with reasonable selection and a complete PCB layout. The software adopts a modular design and is developed based on the C language. It realizes the timed switching logic of signal lights (red, green, yellow lights and countdown), real-time collection and display of environmental parameters (OLED screen), as well as the safety reminder function of “accident mode” based on environmental thresholds (such as showing “SLOW Down!” when the humidity is high).

Looking forward to the future, the research focus will be concentrated on the intelligent upgrade and collaborative expansion of the system: In terms of intelligence, by integrating multi-dimensional data such as vehicle flow and applying intelligent algorithms, the adaptive optimization of signal timing can be achieved; Meanwhile, promote networked collaboration, add communication modules to connect the traffic control center and achieve signal linkage (such as green wave bands) at adjacent intersections; Furthermore, explore the information interaction between vehicle-road coordination (V2I) and connected vehicles.

Conflicts of Interest

The author declares that there is no conflict of interest regarding the publication of this article.

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