Tunnel Lighting Intelligent Control System Based on Ambient Light Ratio

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Abstract. Based on the research problems of modern tunnel lighting control technology, a tunnel lighting intelligent control system based on ambient luminosity ratio is designed, which is characterized by "car close lights bright, car passing lights dark", intelligent analysis of system failures, etc. The core technology is LED Tunnel light group brightness automatic adjustment, python data analysis, etc. The design of the core control unit of the system is based on the STC89C52 chip, which uses the numpy module in python to matrix the data in the database through the information collected by the sensor (the light intensity inside and outside the tunnel, the traffic condition of the vehicle in the tunnel, and the working condition of the tunnel lighting equipment, etc.) Level storage and use principal component analysis and other algorithms to perform a large number of calculations and processing on the obtained data. The controller generates a corresponding PWM signal to control the brightness of the LED tunnel light group to solve the problem of excessive lighting or insufficient brightness; through other controls The components exchange information, and the downstream controller performs calculation and processing according to the control instructions sent by the previous stage and the real-time signals detected by the sensors to realize the selective brightness and automatic brightness adjustment of the tunnel section lighting, and finally achieve intelligent control, energy saving and emission reduction the goal of. In addition, we use the seaborn library and matplotlib library in python to visually display the obtained tunnel lighting equipment working condition data, and send the results to the relevant road management department. This will play an important role in greatly improving the efficiency of activities such as equipment maintenance, collecting equipment work information, and optimizing the work structure of road management. To a certain extent, it is conducive to the implementation of specific work of relevant departments.

Keywords: Tunnel lighting, intelligent control, conserve energy, reduce emissions, Data analysis, LED, PWM.
1. Research background and significance of the project

1.1. Research background
In the context of energy crisis and the worsening global ecological environment, various countries have successively issued various policies to save and reasonably use effective resources. At present, China's highway tunnel lighting system generally adopts the constant light mode, which consumes a lot of power. For example, the annual lighting electricity cost of Xi'an-Hanzhong highway tunnel in Shaanxi Province is close to 23 million yuan, which has become a heavy burden for the highway operation and management department and hindered the implementation of the "national energy conservation and emission reduction strategy".

Aiming at the existing problems of highway tunnel lighting at the present stage, this project designs an intelligent tunnel control system based on environmental luminosity ratio, which can reduce the consumption of lighting energy on the basis of ensuring the safety of tunnel communication, so as to play the role of energy saving and emission reduction.

1.2. Significance of R & D
(1) This project solves the problem that the traditional tunnel lighting can not adjust the brightness;
(2) In response to the theme of "energy saving, emission reduction and green energy", the project solves the problem of high energy consumption caused by the tunnel lighting basically adopts the form of constant light;
(3) The project will supply the most appropriate lighting intensity of the tunnel, which not only solves the problem of insufficient lighting brightness of the tunnel, which is easy to induce drivers' visual fatigue and bring traffic safety risks, but also solves the problem of excessive lighting intensity of the tunnel, which brings waste of electricity.

2. Project design scheme

2.1. General design idea
Based on the research of modern tunnel lighting control, an intelligent tunnel control system based on environmental luminosity ratio is designed. The control system includes: intelligent energy-saving control module, traffic information detector, RS485 bus communication module and several lighting units, traffic information detector, signal input end electrically connected with intelligent energy-saving control module, signal output end electrically connected with intelligent energy-saving control module, RS485 bus communication module electrically connected, and several lighting units are set in parallel and electrically connected with RS485 bus Signal output terminal of communication module. The system structure is shown in Figure 1.

![Figure 1. Structure diagram of intelligent tunnel lighting control system.](image-url)
The control core unit of the controller is designed based on STC89C52, and its arithmetic unit, controller and cache are all completed on the single chip microcomputer, as shown in Figure 2. It can also improve the reliability and flexibility of the system control and reduce the failure rate of the controller. [1]

Based on the literature review of tunnel lighting, a short tunnel can be controlled by one controller, while a long tunnel can be controlled by multiple controllers. Each controller is universal, that is, it can work in any section of the tunnel (entrance section, transition section, etc.). The recognition of working road section is automatically determined according to the received “input control code information”. In addition, in order to simplify the calculation, the outlet section and outlet transition section are set by using the forced jumper. [2]

![Main flow chart of intelligent tunnel control system based on ambient luminosity ratio.](image)

**Figure 2.** Main flow chart of intelligent tunnel control system based on ambient luminosity ratio.
2.2. Working principle

2.2.1. Traffic information detection module. At present, in the traffic detection system or traffic information acquisition system at home and abroad, a large number of high-tech technologies are used, such as electromagnetic sensing technology, ultrasonic sensing technology, radar detection technology, video detection technology, computer technology, communication technology and so on. [3] Accordingly, traffic information detectors mainly include: inductive loop detector (ring induction coil), ultrasonic detector, infrared detector, radar detector, video detector, etc.

Considering the cost performance and high reliability, the ring coil vehicle detector is still used most. [4] This module uses the ground sensing ring vehicle detector, whose function is to detect whether the vehicle has to cross the tunnel. When the vehicle passes the detector, the detector reacts, generates relay signal and transmits it to the main control module, which reacts. The selection of this module is mainly due to its super fast and stable reaction speed. [5] Generally, it can react in 50ms, and the faster one can even reach 35ms. The schematic diagram of the working principle of the ground sensing annular vehicle detector is shown in Figure 4.

![Figure 3](image1.png)

Figure 3. Unit diagram of intelligent tunnel controller based on ambient luminosity ratio.

![Figure 4](image2.png)

Figure 4. Schematic diagram of working principle of ground sensing annular vehicle detector.
2.2.2. Lighting intelligent control module. The intelligent energy-saving control module used in this design includes microprocessor, voltage regulator module, inverter, Darlington transistor drive module and relay module [6]. The input end of voltage regulator module is connected with DC power supply, the first output end is electrically connected with microprocessor [7], the second output end is electrically connected with inverter and Darlington transistor drive module; the inverter is driven by Darlington transistor. The input end of the relay module is electrically connected with the inverter. In this design, the microprocessor uses STC89C52 microcontroller minimum system, and the signal output of the microprocessor can output RS485 communication signal. The structure block diagram of intelligent tunnel control system based on environmental luminosity ratio is shown in Figure 5.

![Figure 5. Structure block diagram of intelligent tunnel control system based on ambient luminosity ratio.](image)

2.2.3. RS485 bus communication module. The RS-485 [8] module used in this design is usually used as a relatively economical communication platform with relatively high noise suppression, relatively high transmission rate, long transmission distance and wide common model range. At the same time, RS-485 circuit has the advantages of convenient control and low cost. In the past 20 years, the proposed standard RS-485, as an electrical specification of multi-point differential data transmission, has been applied in many different fields and played a great role as a data transmission link specification.

At present, RS-485 half duplex asynchronous communication bus is widely used in the field network in our country. [9] However, due to the fact that the bus can only have one host at any time, it is often used between centralized control hub and distributed control unit. The maximum transmission distance of RS-485 standard is about 1219 meters, and the maximum transmission rate is 10Mbps [10]. It uses balanced twisted pair as the transmission medium and has high noise suppression. The appearance diagram of RS485 bus communication module is shown in Figure 6.

![Figure 6. Appearance diagram of RS485 bus communication module.](image)
2.2.4. **Brightness adjustment control module.** Lighting adjustment includes sub controller and LED lighting module. The LED lighting module is electrically connected with the RS485 bus communication module through the self controller. The lighting unit can automatically adjust the brightness of the LED tunnel lamp group according to the lighting conditions in the tunnel, and the brightness meets the specific requirements of "code for design of ventilation and lighting of highway tunnels". At the same time, according to the traffic situation of the vehicle, the tunnel light group is controlled to switch selectively, which makes the tunnel lighting like a bright band with the vehicle moving forward. However, in special cases (such as emergency situations such as excessive traffic flow), the system will automatically set to normally on mode. The control structure of lighting unit system is shown in Figure 7.

![Figure 7. Control structure diagram of lighting unit system.](image)

The key technologies of brightness adjustment control are as follows:

1. **LED light group brightness adjustment**
   - The tunnel light controller collects the traffic condition of the corresponding road section and the real-time brightness information of the tunnel light, and combines it with the received "input control code" interpretation signal for comprehensive calculation, and then generates PWM signal to adjust the brightness of the corresponding road section LED tunnel light group, so as to eliminate the "black hole effect" and "white hole effect", so as to solve the problem of excessive lighting or poor brightness in the tunnel. At the same time, the "input control coding information" needed by the next level control in the calculation results is sent synchronously.
2. **LED light group selective switch**
   - As shown in Figure 16, the "input control coding information" in the entrance tunnel controller is provided by the brightness acquisition and quantization unit of natural light outside the tunnel. The vehicle traffic condition detection component is the key component to realize "the near light is on and the over light is dark". Tunnel lighting real-time brightness detection component is the key component to ensure the safety of driving lighting requirements.
   - The controller and other components are arranged in the tunnel, and the necessary information for the realization of the system function is calculated according to the design speed of the tunnel. In addition, for the long or extra long tunnel, we use the method of dividing it into several sections for layout, so that the system function is not affected, so as to achieve segmented lighting, change the traditional mode of constant light, and save energy to the greatest extent. For example, when a controller detects that a car is passing by, it generates corresponding instructions and transmits them to the next controller to light up the corresponding LED tunnel lamp group. In the process of step-by-step downward transmission, driving in the tunnel is like a bright belt accompanying the left and right (such as controlling the lighting of 150m in front of the vehicle and 20m behind the vehicle). It is
worth mentioning that in the case of excessive traffic flow, accidents and other special circumstances, the system will automatically set to the constant light mode, and at this time the brightness adjustment is still in progress.

3) Master / slave controller structure

Not every control unit in the system must be connected to the "vehicle traffic detection component". If a controller is not connected to the component, it will be automatically controlled by the interpretation signal of "input control coding information" sent by the previous level. For example, the master / slave controller method can be used in the segmented control design of special sections such as long tunnels and sections where dust is easy to accumulate. The structure of master / slave controller is shown in Figure 8.

![Figure 8. Structure diagram of master / slave controller.](image)

3. Project implementation and test analysis

In order to verify the feasibility of the design scheme and the performance of energy saving and emission reduction, a simulation development environment of tunnel lamp brightness control and light brightness control is built in the laboratory to simulate the new energy-saving tunnel lighting control function when the actual driving is passing, and detect the function of "car approaching light is on, car walking light is dark" and the change of automatic brightness adjustment of the new energy-saving tunnel lighting control when the light is on. The energy saving and emission reduction data of the system are calculated through the electricity meter.

3.1. Realization and test of light and dark control function of tunnel lamp

The appearance and component diagram of the tunnel light dark control system are shown in Figure 9, which is composed of STM32, relay, photoelectric sensor and LED light. The system detects vehicle flow and vehicle passing status through photoelectric sensor, and transmits relevant information to MCU for relevant processing. Then MCU controls relay to realize the connection and disconnection of LED.

![Figure 9. Schematic diagram of appearance and components of tunnel light dark control system.](image)

Before there is no vehicle, the control system makes the LED in a dark state. When the vehicle arrives at the detection position of the photoelectric sensor, the photoelectric sensor recognizes and inputs the signal to the single chip microcomputer for processing. The single chip microcomputer turns on the relay to make the LED light bright. At the same time, the system starts timing (set the interval of 5 seconds, if there is no vehicle passing, the system will automatically dim the light). If
there is no other vehicle passing after 5 seconds, the system will turn off the LED; if there are other vehicles passing within 5 seconds, the system will keep the LED on until the photoelectric sensor has not detected the vehicle passing after 5 seconds, the system will automatically dim the light Dim the led to realize the function of controlling the tunnel light switch and achieve the purpose of energy saving and emission reduction.

In the laboratory test, three vehicles are used to realize the function of light and dark control in four different situations: before the driving vehicle arrives at the test area, when the driving vehicle arrives at the test area, after the driving vehicle passes through the test area, and when the driving vehicle is far away from the test area. After that, through the form of cycle traffic flow, the most frequent led on and off frequency is simulated. Through the comparison with the power consumption of constant light in the same time, whether the switch control system has the experimental data of energy saving and emission reduction is obtained.

![Figure 10. Before car a reaches the detection area.](image)

As shown in Figure 10, three different vehicles simulate the situation of cycle vehicles, named car a, car B and car C in turn. Car a is in the process of driving and is about to reach the monitoring area. At this time, you can see that the LED is dim.

As shown in Figure 11, when the car a passes through the detection area, when the photoelectric sensor detects that there is an obstacle passing by, it sends the corresponding command to the MCU, and the LED lights up at this time.

![Figure 11. When car a reaches the detection area.](image)

As shown in Figure 12, after car a passes through the detection area, because the set led duration is 5S, the LED still remains bright within the duration.
Figure 12. After car a passes through the detection area.

As shown in Figure 13, after car a is far away from the detection area, when the preset duration is exceeded and there is no vehicle passing behind, the light on control system drives the led to dim. At this time, the LED is in a dim state. When car B and car C pass through the detection area, the continuous light and dark conditions are shown in Figure 14.

Figure 13. Car a far away from the detection area.

Figure 14. Light intensity of car B and car C passing through the detection area.

3.2. Implementation and test of LED brightness control function
The light brightness control system is built by the team members independently. The light brightness control system is connected with the light sensor module, and the LED light is used as the load to test. All components of the LED are welded on a 9cm * 15cm universal board. The middle part is the
minimum system of single chip microcomputer, including reset circuit and clock (crystal oscillator) circuit. The power and ground are respectively led out by row pins, which is convenient for other modules to reference. The top left corner of the universal board leads out five rows for the light sensor module, and the top and middle right part just leads out 16 rows for the LCD 1602. The appearance diagram and components of light brightness control system are shown in Figure 15.

![Figure 15. Light brightness control system appearance and system diagram.](image)

As shown in Figure 16, in different lighting environments, the degree of light regulated by the light brightness control system is different. The darker the lighting environment, the brighter the light intensity presented by LED after intelligent detection and comparison, and the more obvious the lighting effect of the light brightness control system.

![Figure 16. Light intensity change comparison diagram of light brightness control system in different brightness environment.](image)

3.3. Design and implementation of control system function interface

In order to better combine the hardware and software of the intelligent tunnel control system and optimize the human-computer interaction, the operation interface is designed with QT under the environment of installing Ubuntu 14.04 on the PC, as shown in Figure 17.
The interface has the functions of file, edit, create, switch user, window, help and exit on the menu bar. It can load files, edit data and set up tasks in different periods according to the actual needs of users, and it can correspond to the corresponding operations according to the permissions of different users. When you log in as an operator, you can use the open, close, self check, always on, intelligent, strong medium weak operation under the operation button, but you can't carry out system operation such as analysis and alarm. Only when the user is switched to the administrator role can the analysis and alarm functions be used. The interface assigns different functions and permissions to different roles, and has strong confidentiality.

3.4. System LED energy saving and emission reduction performance index test
Through the test, the brightness control function and the LED control function of the intelligent tunnel control system based on the ambient luminosity ratio are all normal. Through the simulation test, it has successfully realized "the car near light is on, the car passing light is dark"; and it can adjust the most suitable driving lighting environment when the LED is turned on. Through the analysis of the test data, the comparison of energy saving and emission reduction performance indicators is shown in Table 1 and table 2.

**Table 1.** Compares three 1.2m 36W incandescent lamps with three 15W lighting control systems.

| Performance comparison | Traditional incandescent lamp | LED light |
|-------------------------|-------------------------------|----------|
| Single light effect     | 40lm/W                        | 95lm/W   |
| Types of lamps and lumens | 1.2m 40W fluorescent lamp | 3W round LED light combination | First 3W lighting control system |
| Actual power            | 40W                           | 15W      | 9W | 10.5W | 12W |
| Actual luminous flux    | 1350                          | 1400     | 850 | 1000 | 1150 |
| Annual electricity consumption (10 hours per day) | 40W×10h×365W=4380 38 | 15W×10h×365W=164 | 9W×10h×365W=99 | 10.5W×10h×365W=115 | 12W×10h×365W=131 |
| Annual electricity change (10 hours per day) | 438×0.8=350 | 164×0.8=131 | 99×0.8=79 | 115×0.8=92 | 131×0.8=105 |
| Carbon dioxide from electricity generation in a year | 435kg | 162kg | 98kg | 114kg | 130kg |
According to the above experimental data, it is concluded that:

1. Compared with ordinary LED lighting system, this project can save energy about 36% and reduce carbon dioxide emission about 40%;
2. Compared with the traditional incandescent lamp lighting system, this project can save about 75% energy and reduce about 74% CO2 emission;
3. This project can not only meet the actual driving needs of the lighting environment, but also achieve high efficiency and energy saving, reduce the possibility of inducing traffic accidents, but also have objective economic benefits, which can provide reference for the intelligent control technology of tunnel lighting at this stage.

3.5. Test conclusion

The intelligent control system of tunnel lighting based on the environmental luminosity ratio analyzes the different characteristics of whether the vehicle enters the tunnel and the actual lighting environment when driving in the tunnel. The photoelectric sensor detects the light on and the lighting sensor detects the environmental brightness in real time [11], and calculates and adjusts the most appropriate driving safety lighting environment data. Through the experimental test, this project is in good agreement with the traditional tunnel lighting. It can achieve the expected functions such as light and dark control, light brightness change adjustment and so on. It is in line with the characteristics of modern traffic intelligent control, and can reduce the burden of urban power consumption [12], play the role of energy conservation and emission reduction.

4. Innovation and Application

4.1. Innovation

1. In the adjustable lighting system, combined with intelligent control of tunnel lighting as the research direction, an intelligent tunnel lighting control system based on environmental luminosity ratio is designed, which is an innovative design idea;
2. The installation of the project will not cause damage to the highway. The intelligent control of lighting LED lights can effectively reduce the waste of energy and greatly reduce the waste of power resources when there is no driving. In the aspect of energy saving control, the project is an excellent application innovation;
3. Compared with the traditional fixed tunnel lighting mode, the project adjusts the most suitable lighting environment parameters by detecting the real-time lighting environment and controlling the
lighting brightness and dimming of the actual vehicles. It is a practical application angle and technical innovation for the energy-saving lighting of the tunnel.

4.2. Application prospect
(1) At present, there is no intelligent tunnel lighting control system to adjust the light intensity in the market. The intelligent tunnel lighting control system based on the ambient photometric ratio can dynamically turn on and off the lighting system according to the detection data of the actual traffic situation, and adjust the most appropriate driving safety environment parameters according to the real lighting environment [13], which can reduce the economic cost and reduce the light problem [14]. The possibility of causing traffic accidents;

(2) The light brightness can be adjusted to greatly reduce the power consumption of the tunnel lighting control system. While reducing a large number of harmful gases such as sulfur dioxide and nitrogen compounds and greenhouse gases [15] such as carbon dioxide, it can improve people's living and travel environment and reduce the power burden of the city;

(3) The combination of intelligent tunnel energy-saving lighting [16] and communication system is in line with the application innovation direction under the background of today's "intelligent transportation", making urban traffic management more humane and intelligent.

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