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Application Strategies of Automatic Addressable Single-Lamp Control Technology in Tunnel Lighting

Huiyan Yang*

China Merchants Chongqing Communications Technology Research & Design Institute Co., LTD., Chongqing 400067, China

***Corresponding author:** Huiyan Yang, lista5862357@163.com

Abstract: The article mainly studies the application strategy of automatic addressable single-lamp control technology in tunnel lighting. It encompasses an introduction to this technology, an analysis of the tunnel lighting system using automatic addressable single-lamp control technology, and outlines the main development direction for this technology in modern tunnel lighting. The aim is to offer insights that can inform the rational deployment of this technology, thereby enhancing the lighting control effectiveness in modern tunnels and meeting their specific lighting requirements more effectively.

Keywords: Tunnel lighting; Automatic addressable single-lamp control technology; System design; Cascade control

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1. Introduction

When designing tunnel lighting systems with automatic addressable single-lamp control technology, designers and technicians need to grasp the fundamental principles, components, and functions of this technology. Using this knowledge as a foundation, they can then integrate it effectively into the tunnel lighting system based on real-world conditions. Furthermore, researchers should consider the current usage and future requirements of tunnel lighting systems to steer the development direction of automatic addressable single-lamp control technology. This approach ensures that the technology's benefits are maximized to fulfill the practical lighting control needs of modern tunnel systems.

2. Automatic addressable single-lamp control technology

2.1. Basic principle

The core principle of automatic addressable single-lamp control technology involves gathering data via sensors connected to an automatic addressable controller. This controller collects various information, preprocesses it, and then transfers it to the monitoring equipment computer system [1]. Subsequently, the computer system further analyzes the data and sends corresponding control instructions to the automatic addressable controller to regulate the lighting conditions within the tunnel.

2.2. Main components

The automatic addressable single-lamp control system comprises several key components, including sensors, a network transmission system, a remote control center, and automatic addressable controllers. Sensors are primarily tasked with gathering lighting information within the tunnel, while the network transmission system facilitates real-time communication between the sensors and the remote control center. The computer within the remote control center serves as the upper computer, responsible for analyzing and processing the lighting information collected by the sensors. Lastly, the automatic addressable controller responds to control instructions from the remote control center, enabling automated control of the tunnel lighting conditions.

2.3. Features

Automatic addressable single-lamp control technology exhibits several key features.

(1) Real-time display and control

Utilizing a touchscreen interface, the current status of tunnel lighting equipment can be displayed to staff in real-time. Staff members can issue control instructions directly through the touch screen, enabling remote control of tunnel lighting conditions.

(2) Independent operation

The automatic addressable controller functions as an independent device. In the event of equipment failure or signal interruptions, the controller can continue to operate autonomously. Staff can switch to manual mode to remotely control tunnel lighting under such circumstances.

(3) Data transmission to monitoring center

Operational data from the automatic addressable controller can be transmitted in real-time to the monitoring center computer. This allows staff to manually control the system and make adjustments as necessary.

These features collectively contribute to the widespread adoption and notable advantages of automatic addressable single-lamp control technology in modern tunnel lighting systems.

3. Analysis of tunnel lighting system based on automatic addressable single-lamp control technology

3.1. System composition

In modern tunnel lighting systems, RS485 stands out as the most typical and widely employed automation and intelligent control system. The system's key components encompass a remote monitoring platform, sensor equipment (comprising light sensors inside and outside the tunnel, along with microwave detection sensors), a gateway (primarily for the lighting control cabinet or centralized controller), and terminal equipment (mainly for the RS485 drive power supply). Additionally, designers can incorporate RS485 repeaters as needed based on the tunnel project's length and the number of lighting applications. This approach enables comprehensive automation of brightness management and control for all lighting fixtures within the tunnel. Communication methods for each component of the system include: (1) The monitoring center primarily communicates via fiber optic network channels or GPRS channels. (2) RS485 repeaters communicate mainly through the RS485 channel [2]. (3) RS485 drive power interfaces communicate via the RS485 channel. (4) Centralized controllers primarily communicate through the RS485 channel. **Figure 1** illustrates a schematic diagram depicting the overall topology of the tunnel lighting system supported by automatic addressable single-lamp control technology.

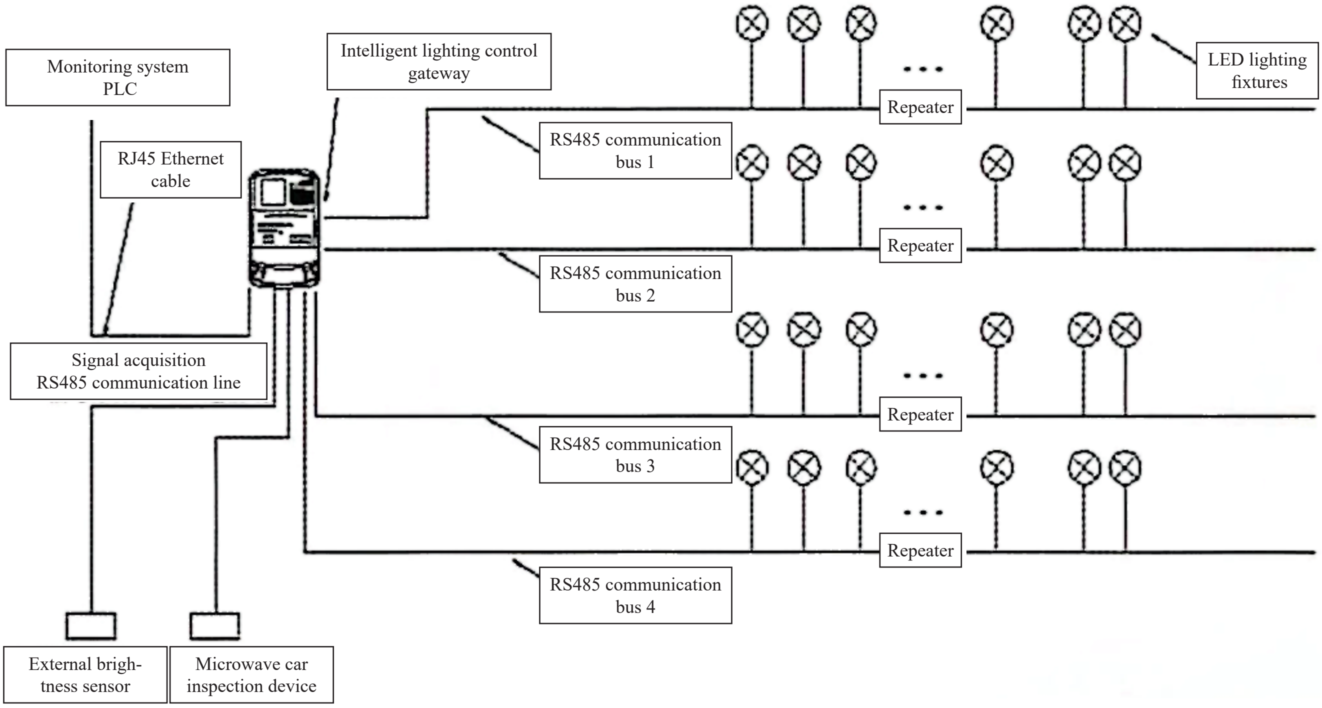

Figure 1. Schematic diagram of the overall topology of the tunnel lighting system supported by automatic addressable single-lamp control technology

3.2. Application of basic system functions

Under the support of automatic addressing single-lamp control technology, the fundamental control functions of a tunnel lighting system encompass various modes.

3.2.1. Realization of multiple control modes

(1) Manual control mode

his mode allows staff to adjust the brightness of each lighting section within the tunnel manually via the remote monitoring platform. Factors such as real-time weather conditions, external brightness, and traffic flow information are considered. Staff can send control instructions to the centralized controller through the platform, which then distributes corresponding instructions to the relevant lighting fixtures in the tunnel. In emergency situations, such as a fire inside the tunnel, staff can initiate a 100% dimming command, ensuring maximum brightness to prevent traffic accidents.

(2) Scene control mode

Staff can configure sensor detection parameters, enabling the system to automatically adjust the lighting brightness of each tunnel section based on external light, traffic flow, and vehicle speed data. This results in seamless dimming control to suit varying conditions. In the event of a control system failure, the tunnel lighting brightness is automatically set to 100% to maintain illumination levels and prevent accidents.

(3) Schedule control mode

During the nightly period from 19:00 to 07:00, when external ambient light remains relatively stable, the system divides the time into two segments: the first half of the night (19:00 to 00:00) and the second half (00:00 to 07:00). During peak traffic hours in the first half, the tunnel lighting operates at full power. In the latter half, with reduced traffic, lighting brightness is adjusted accordingly, optimizing energy usage while ensuring sufficient illumination for safety.

3.2.2. Diverse monitoring methods

(1) With the preset, automatic, and manual control modes, personnel can remotely switch and adjust the brightness of each lighting fixture in each lighting section of the tunnel, and monitor their current, voltage, power, and power factor in real time, thereby achieving real-time control of the operation status of each fixture [3].

(2) With the preset, automatic, and manual control modes, personnel can remotely switch and dim all circuits in each lighting section, and monitor their current, voltage, power, and power factor in real time, thereby achieving real-time control of the operation status of all circuits.

(3) With the preset, automatic, and manual control modes, personnel can remotely switch and dim all fixtures in the entire tunnel, and monitor their current, voltage, power, and power factor in real time, thereby achieving real-time control of the operation status of all lighting fixtures [4].

3.2.3. Automatic report of lighting failure information

In the event of a tunnel lighting fixture failure, the centralized controller promptly notifies staff of the fault information. Detailed data, including the location of the faulty lamps, the cause of the failure, and other pertinent information, is provided to facilitate swift operation and maintenance activities. This proactive reporting mechanism ensures that staff have the necessary information at their disposal to efficiently address any issues and minimize downtime in the tunnel lighting system.

3.2.4. Collection of tunnel illumination, traffic flow, and traffic speed data

The system can gather data on external and internal illuminance, traffic flow, and vehicle speed within the tunnel. This data serves as the foundation for developing scientifically optimized dimming programs for the internal lighting fixtures of the tunnel. Through automatic management and adjustment of brightness levels, the system aims to prevent phenomena such as the black hole effect or the white hole effect, thereby maximizing energy savings in tunnel lighting while ensuring optimal visibility for vehicles entering and exiting the tunnel.

3.2.5. Data query

The system's remote monitoring platform continuously updates in real-time to store data. Staff members can access the platform's database in real-time to monitor the actual operation of the tunnel lighting fixtures.

3.2.6. Security management

Different users of the system are assigned varying application permissions based on their respective identities. This tailored approach helps prevent staff from making incorrect settings, thereby maximizing the overall system's ability to ensure the safety of tunnel lighting. Additionally, the system features a map guide functionality where the locations of all lighting fixtures are displayed on a map. Within the map guidance interface, staff can query and locate the tunnel lighting rate as well as identify faulty lamps [5].

3.3. Cascade control method of the system

Under the support of automatic addressing single-lamp control technology, the primary cascade modules of an RS485-based tunnel lighting control system consist of the AC-DC module, MCU module, DC-DC module, RS485A module, and RS485B module. In the specific cascade control process, the basic principles include the following: (1) The AC-DC module facilitates the generation of multiple DCs, supplying power separately to the MCU module and DC-DC module at the backend. (2) The MCU module, with assistance from the RS485A or RS485B module, collects control commands and transmits PWM dimming signals to the DC-DC module. Upon receiving the dimming signal, the DC-DC module regulates current based on the PWM duty cycle. Additionally, the MCU forwards acquired control instructions to the next drive power supply via the RS485A or RS485B module, ensuring effective cascade signal transfer. (3) The DC-DC module provides feedback on output current or voltage signals to the MCU, allowing for informed judgments on power supply operation. These signals can also be transmitted to centralized control via the RS485A or RS485B module interfaces.

In specific applications, the cascade control mode offers the following main features: (1) Automatic addressing and paper copying functions streamline the installation process by eliminating the need for manual address transcription and fixture positioning. This results in significant savings in manpower, time, and labor costs. (2) The combination of multiple control modes enhances precision in controlling each lighting fixture within the tunnel, ensuring optimal lighting conditions [6]. (3) The status query function enables staff to monitor the real-time operation of each lighting fixture in the tunnel, facilitating quick identification of faulty lamps. (4) The fault feedback and localization function automatically alerts staff to lighting fixture or equipment failures, enabling prompt response to resolve the issue. This proactive approach ensures timely fault management and system maintenance.

3.4. Main performance characteristics of the system

In the context of the current automatic addressable single-lamp control technology, the main features of the tunnel lighting system are as follows: (1) In the event of communication failure between the monitoring center and the gateway, all tunnel lamps automatically adjust to 100% brightness to ensure effective traffic operations [7]. (2) The overall system control mode operates on a feedback basis, where all data is processed and uploaded to the control platform. The platform further analyzes the data and issues corresponding remote control commands based on the actual situation. (3) The system autonomously reports single-lamp power supply, communication, and various fault alarms (such as over-current, over-voltage, and under-voltage) to the control system, enabling prompt staff intervention. (4) RS485 bus allows stable communication of this system. (5) The system achieves on-demand lighting while meeting tunnel lighting requirements, leading to a rational reduction in power loss and lighting costs [8]. (6) During tunnel maintenance or in abnormal situations, the system automatically adjusts all lamp powers to 100% to maintain adequate lighting and prevent traffic accidents.

4. Main development direction of automatic addressable single-lamp control technology in modern tunnel lighting

automatic addressable single-lamp control technology offers significant application advantages in modern tunnel lighting systems [9]. To align with the practical demands and evolving requirements of modern tunnel lighting systems, this technology also needs to progress in more advanced directions.

(1) High integration development

Integrating more advanced integration technology and equipment to enhance the technology and application functions of tunnel lighting systems. This aims to achieve higher integration effects, meeting the automation and intelligent control needs of tunnel lighting effectively.

(2) Simplification

Developing more advanced sensor equipment to streamline the system by reducing the number of sensors installed in the tunnel. This simplification enhances the overall system functionality and promotes the advancement of the technology towards simplicity.

(3) Artificial intelligence development: Leveraging advanced robots to support tunnel lighting systems, replacing the need for on-site operation and maintenance staff to address lighting faults. This approach significantly improves the response speed for addressing faulty lamps, enhances maintenance efficiency and quality, and reduces labor costs [10].

5. Conclusion

Automatic addressing single-lamp control technology stands as a pivotal technology in modern tunnel engineering lighting control. Therefore, researchers and technicians should possess a comprehensive understanding of this technology to facilitate its rational application in tunnel lighting. By implementing a well-constructed and applied tunnel lighting automation control system, the lighting effect of modern tunnels can be effectively enhanced, meeting the safety requirements during actual operation.

Disclosure statement

The author declares no conflict of interest.

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