Design of Single-lamp Monitoring System for Airfield Lighting Based on Broadband Power Line Carrier Communication

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Abstract: Considering the problems of low communication rate and large communication delay of the traditional single-lamp monitoring system for airfield lighting based on narrow-band power line carrier communication technology, a solution of single-lamp monitoring system for airfield lighting based on broadband power carrier communication technology is proposed. Firstly, this paper has made a comparison of advantages and disadvantages between narrow-band power line carrier communication technology and broadband power line carrier communication technology, and briefed the problems faced by traditional single-lamp monitoring system based on narrow-band power line carrier communication. Taking technical characteristics into consideration, broadband power line carrier communication technology is selected for the development of a new single-lamp monitoring system for airfield lighting. Secondly, this paper articulated the design and development process of new airfield lighting single-lamp monitoring system based on broadband power line carrier communication technology, from the formulation of the overall architecture scheme of the system to the realization of local convergent equipment, and focused on the analysis of hardware and software development process of single-lamp monitoring module. Finally, this paper set up a test environment, and verified the performance index by experiments. The test results show that the system meets the design index requirements, can improve the performance of the single-lamp monitoring system for airfield lighting, effectively solves the problems faced by the traditional system, and can further meet the needs of the airport for airfield lighting monitoring and control.

1. Introduction
The power supply circuit of airfield lighting is composed of constant current dimmer, isolation transformer, primary power cables and airfield lighting, which is an important part to ensure the normal operation of the airport and a necessary visual navigation aid for aircraft to take off, land and taxi smoothly at night under complex weather conditions [1]. With the deepening of the concept of smart airport in the field of civil aviation, the airport is in urgent need of new single-lamp monitoring system for airfield lighting to realize single-lamp monitoring and control of airfield lighting. Besides, the Advanced-Surface Movement Guide and Control System (A-SMGCS) [2], which provides advanced path guidance for aircraft taxiing is adopted to improve the airport’s operating efficiency and reduce carbon emissions [3].
At present, the power line carrier technology is mainly divided into broadband power line carrier technology and narrow-band power line carrier technology [4]. For the narrow-band power line carrier technology, it adopts BPSK or spread spectrum modulation, the communication protocol is Lonworks with various self-owned protocols, the carrier frequency is ranging from 9 kHz to 500 kHz, and the communication rate is less than 200 kbps. For the broadband power line carrier technology, it adopts high-performance modulation methods such as OFDM, the communication protocol is TCP/IP or UDP protocol, the carrier frequency is ranging from 2 M to 34 M, and the communication rate is greater than 1Mbps [5-6].

The traditional single-lamp monitoring system for airfield lighting basically adopts narrow-band power line carrier communication technology. Due to the influence of isolation transformer and lighting load in airfield lighting circuit, the high-frequency power line carrier signal is attenuated greatly and the system parameter modulation is difficult to deal with. At the same time, the power supply line of non-sinusoidal wave constant current dimmer contains a large number of harmonic components, which makes unpredictable noise and interference sources in the circuit [7]. In practical application, although narrow-band has the advantages of long transmission distance and crossing isolation transformers, the maximum communication rate is 10 kbps [6-9], and the communication delay only meets the standard requirement value of 2 s [10]. The poor system performance cannot fully meet the business requirements of airport users for single-lamp monitoring and control.

With the obvious advantages of broadband power line carrier in communication rate and communication delay, using high-performance modulation methods such as OFDM and perfect relay network mechanism [11], this paper has proposed a solution of single-lamp monitoring system based on broadband power line carrier communication, which enables the new single-lamp monitoring system with monitoring and control functions, as well as the following performance indexes: the accuracy of single-lamp control is greater than 99.9%; the two-way communication delay of the system is less than 1.2 s; the maximum communication rate of the system is more than 500 kbps. This paper is going to describe how to use broadband power line carrier communication technology to realize the development of a new single-lamp monitoring system for airfield lighting. Through experiments, it verifies whether the system has the lamp monitoring and control functions and meets the requirement of the design performance index.

2. Design of System Architecture

This system adopts the distributed working mode of computer-centralized control and distributed data acquisition [12], and its system architecture is shown in Figure 1 below.

The system includes: computer server, local convergent equipment, single-lamp monitoring module and signal coupling unit. The computer server communicates with the local convergent equipment through the Internet, and the local convergent equipment uses the main core of primary power cables
and shielding layer of the airfield lighting circuit to exchange data with the outfield single-lamp monitoring module. The computer server is used for monitoring the state of remote equipment and sending control commands. The data of local convergent equipment is used for equipment management, data aggregation and forwarding. The single-lamp monitoring module realizes the monitoring and control of airfield lighting. The signal coupling unit is connected in parallel at both ends of the isolation transformer, which is used to couple the power line carrier signal and reduce the attenuation of the power line carrier signal of the isolation transformer [13].

After the front-end communication module of the local convergent equipment and the back-end communication module of the single-lamp monitoring module are powered on, according to the network environment and configuration parameters, the back-end communication module automatically initiates networking. After the whole network is optimized and converged, the communication link network topology forms a relatively stable tree-like structure, as shown in Figure 2. This structure has relay transmission function, and supports 16th-level relay at most to ensure long-distance transmission of the system [14]. Even if the circuit environment changes during operation, the communication link can set relay nodes through auto negotiation, optimize transmission routes and ensure the best transmission path.

![Figure 2. Tree topology diagram of system communication link networking.](image)

3. Design of local convergent equipment

How to realize back-end equipment management and local-end data aggregation and forwarding is the primary problem that local convergent equipment needs to solve.
According to the business requirements of local convergent equipment, a solution of local convergent equipment is put forward, as shown in Figure 3, which includes the core board of edge computing and front-end communication module. Extended network interface is used to exchange data between them, and IP-based PLC-IoT network is used to realize back-end equipment management and office-end data aggregation and forwarding. The core board of edge computing is used for uplink and downlink data interaction as well as front-end and back-end communication modules management. It has built-in LXC container [15], which facilitates the deployment and running of third-party APP software, realizes business functions required by users, and supports RTC temperature detection, brown-out detection, container management, secure boot, whitelist certificate authentication, data encryption TCP, UDP, ICMP, IPv4, IPv6, etc. [16] The front-end communication module processes, analyzes and couples broadband power line carrier communication signals, uploads or downloads data through broadband power line carrier communication technology, and realizes remote monitoring and control of terminal equipment. The working frequency supports the range from 2M to 12M, and the communication interface supports strong and weak current interfaces.

The data flow of local convergent equipment includes uplink and downlink data flow. Downlink data flow means that the core board of edge computing will receive the data from computer server through its Ethernet GE0 port, analyze, process and forward the front-end communication module by APP software built in the container, and then the front-end communication module will encode and modulate the data into power line carrier signals and couple it to the power cables. Uplink data flow means that the front-end communication module demodulates and decodes the power line carrier signal from power cables, passes the parsed data packet to the core board of edge computing through the network expansion port, then processes it by APP software built in the container, and finally transmits the data to the computer server through the GEO port.

4. Design of Single-lamp Monitoring Module

4.1 Hardware design
The scheme of single-lamp monitoring module is shown in Figure 4. The single-lamp monitoring module can realize airfield lighting monitoring control and remote data interchange, and includes back-end communication module and main monitoring module. The back-end communication module has the function of data acquisition, uploads or downloads data through broadband power line carrier communication, and realizes remote data interchange. The working frequency ranges from 2 M to 12 M, and the communication interface supports strong and weak current interfaces. The main monitoring module is connected in series between the isolation transformer and the airfield lighting by using the auxiliary cable connectors, which can collect the current and voltage parameters of the airfield lighting and the temperature and humidity values inside the module, and control the on-off of airfield lighting in response to the control commands.
Inside the module, the back-end communication module uses serial UART interface to exchange data with the main monitoring module, and the main monitoring module provides 12V DC power supply to the back-end module. The private broadband power line carrier communication interface outside the single-lamp monitoring module is directly connected with the external signal coupling unit to realize the transmission coupling of broadband power line carrier signals. The secondary cable connector is respectively connected with the isolation transformer and the airfield lighting, and provides AC constant current power supply to the single-lamp monitoring module and the airfield lighting.

4.2 Software design

The application layer data between the computer server and the single-lamp monitoring module adopts the communication protocol as shown in Figure 5. The data message starts with the “DB09” STX and ends with the “00AA” ETX. The intermediate data covers the data length, payload and CRC. The data length and payload can be checked by CRC to ensure the reliability of application layer data messages.

| STX(EB90) | Data length | Payload | CRC | ETX(00AA) |
|-----------|-------------|---------|-----|-----------|

Figure 5. Communication protocol.

The software program of single-lamp monitoring module adopts wake-up interrupt mechanism with low power consumption. The software flow chart is shown in Figure 6. After the single-lamp monitoring module is powered on, hardware such as clock, peripherals and interrupt are initialized, and it is determined whether the module is successfully networked. After the module is successfully networked, the voltage and current acquisition module and the temperature and humidity acquisition module are started, and then it moves to the hibernation mode. When an event triggers the interrupt instruction, it will awake the MCU to process the corresponding event [17].
Figure 6. Software flow chart of single-lamp monitoring module.
5. Experimental Results
The single-lamp monitoring system based on broadband power line carrier communication is composed of computer server, local convergent equipment, single-lamp monitoring module and signal coupling unit. The field test environment includes 105 sets of single-lamp monitoring modules, a set of local convergent equipment, a set of computer server and 105 sets of signal coupling units, which are used to build a single-lamp monitoring system for airfield lighting based on broadband power line carrier communication. The schematic diagram of the test environment is shown in Figure 7. In order to accurately verify the function and performance of the single-lamp monitoring system for airfield lighting based on broadband power line carrier communication, a series of experiments will be carried out on the monitoring function, control accuracy, communication rate and communication delay of the system.

Figure 7. Schematic diagram of test environment.

5.1 Monitoring function experiment

5.1.1 Experimental content. 105 sets of single-lamp monitoring modules in the test site are numbered sequentially from TC001 # to TC105 #, and map module numbers, mac and ipv6 addresses respectively to form a mapping table. First, the online status of the back-end communication module is checked through the local convergent equipment. If 105 sets of back-end communication modules enter the online status, manually query to get the ipv6 addresses of all modules, and then use the ping6 tool to test all modules in turn to verify whether the communication link layer remains connected [18]. Secondly, when ping6 passes through all modules, it sends query commands from the computer server interface to observe whether the single-lamp monitoring module feeds back state data, and tests 10 groups in total to verify whether the single-lamp monitoring module has monitoring function. Finally, after ping6 passes through all modules, control commands are sent from the computer server interface, including lights on command and lights off command, to observe whether the single-light monitoring module acts correctly, and feed back state data, and test 10 groups in total to verify whether the single-light monitoring module has control function.

5.1.2 Basis of judgment. 1) In terms of local convergent equipment, whether ping6 can pass through all back-end communication modules? 2) In terms of the computer server interface, send a query command to the single-lamp monitoring terminal and check whether the module reports the state information? 3) In terms of the computer server interface, send the control command to the single-lamp monitoring terminal and check whether the module acts and responds correctly and reports the state information?

5.1.3 Experimental results. 1) In a single experiment, ping6 passes through all 105 sets of back-end communication modules, and the addressing access accuracy is shown in Figure 8.
2) In multi-group experiments, the experimental results of monitoring and control functions of all single-lamp monitoring modules are shown in Table 1, and all single-lamp monitoring modules have monitoring and control functions.

| Number of experimental groups | Monitoring function of all single-lamp monitoring modules? | Control function of all single-lamp monitoring modules? |
|-------------------------------|----------------------------------------------------------|-------------------------------------------------------|
| 10                            | YES                                                      | YES                                                  |

5.1.4 Experimental results. The experimental results show that the addressing accuracy of all single-lamp monitoring modules is 100%, the communication links maintain stable connection, and the system has monitoring and control functions.

5.2 Control accuracy

5.2.1 Experimental content. To cover all nodes in the test environment, and ensure the number of tests, single-lamp control is conducted on 105 sets of single-lamp monitoring modules in the test environment through computer server software. 10 groups of lights on control commands and lights off control commands respectively are sent alternately in the experiment, with a total of 2100 times of single-lamp control. The state information fed back by the modules on the computer server software is observed and counted to verify whether the accuracy rate of single-lamp control of the system is greater than 99.9%.

5.2.2 Basis of judgment. After the control command is issued, does the single-lamp monitoring module correctly respond to the command and feed back the state information?

5.2.3 Experimental results. A total of 2100 single-lamp control experiments are carried out, and the experiment results are shown in Table 2. The measured single-lamp control accuracy rate in this experiment is 100%.
5.2.4 Experimental results. Through the above-mentioned experiments, it is verified that the single-lamp control accuracy of the system is higher than 99.9%, which meets the design requirements.

5.3 Communication delay

5.3.1 Experimental content. From 105 sets of single-lamp monitoring modules, 87 sets of modules are randomly selected for single-lamp control tests, and the lights on and lights off commands are alternately sent on the software interface of computer server, and the time of sending control commands is recorded. When the server software interface receives the feedback state information of the module, it records the time of receiving the feedback state information, finally calculates the two-way communication delay of the system, and verifies whether the two-way communication delay of the system is lower than the design value of 1.2 s.

5.3.2 Basis of judgment. Is the system’s two-way communication delay of each experimental group less than 1.2 seconds?

5.3.3 Experimental results. With 10 experimental groups, the two-way communication delay results of 87 sets of single-lamp monitoring modules are detected, as shown in Table 3.

| Number of experimental groups | Average delay (ms) | Minimum delay (ms) | Maximum delay (ms) | Design requirement value (s) |
|------------------------------|--------------------|--------------------|--------------------|-----------------------------|
| 1                            | 141.10             | 32                 | 863                | <1.2                        |
| 2                            | 134.52             | 39                 | 904                | <1.2                        |
| 3                            | 141.52             | 34                 | 871                | <1.2                        |
| 4                            | 129.49             | 41                 | 784                | <1.2                        |
| 5                            | 150.53             | 38                 | 898                | <1.2                        |
| 6                            | 126.59             | 36                 | 831                | <1.2                        |
| 7                            | 155.79             | 37                 | 938                | <1.2                        |
| 8                            | 127.92             | 39                 | 802                | <1.2                        |
| 9                            | 164.34             | 35                 | 834                | <1.2                        |
| 10                           | 131.11             | 39                 | 1006               | <1.2                        |

As can be seen from Table 3, the average delay of system’s two-way communication is less than 200 ms, the minimum delay is 32 ms, and the maximum delay is 1006 ms.

5.3.4 Experimental results. Through the experimental results above, it shows that the system’s two-way communication delay is far lower than the standard requirement of 2s and is better than the design requirement value of 1.2 s.

5.4 Communication rate

5.4.1 Experimental content. Through configuring the test script file, the total number of test packages is fixed to 1000, and the over time for receiving reply messages fixed to 2s. The control variable method is used to dynamically configure the following three parameters, with the package sending interval no less than 20ms, and the message load length in the range of 32 ~ 1500 bytes. The ipv6
address is set by reasonably selecting nodes, and the maximum communication rate of the system under the current test environment is tested by loopback test module.

5.4.2 Basis of judgment. The test results are regarded as qualified if they meet the following conditions, with the successfully sent rate greater than 99.9%, and the communication delay less than 1.2 s.

5.4.3 Experimental results. After many experiments, when the node adopts fe00::2a4:ff:fe43:6531, the package sending interval is set as 20 ms, the message load length is set as 1430 bytes, and the tested maximum communication rate of the system is 520 kbps, as shown in Figure 9.

5.4.4 Experimental results. The above-mentioned experiments show that under the current test environment, the maximum communication rate of the single-lamp monitoring system based on broadband power line carrier communication is 520 kbps, which meets the design requirements of 500 kbps, obviously superior to the narrow-band single-lamp monitoring system.

6. Conclusion
This paper has studied the architecture of single-lamp monitoring system based on broadband power line carrier communication, explains realization method of local convergent equipment, and focused on the analysis of design and development process of single-lamp monitoring module. Through local convergent equipment and single-lamp monitoring module, the monitoring and control of airfield lighting were realized, the development of single-lamp monitoring system for airfield lighting based on broadband power line carrier communication technology was completed. And then by building a test environment, the function and performance of the new single-lamp monitoring system was verified. The experimental results show that the function and performance of the system meet the design requirements and are superior to the traditional single-lamp monitoring system, which can meet the system’s performance requirements of airport users and provide a new direction for the development of intelligent light guidance system in civil airports.

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