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Street Lamp Status Warning System Based on Internet of Things Technology

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Abstract: This paper proposes a street light warning system based on Internet of Things (IoT) technology, which uses cameras to detect moving targets such as vehicles and pedestrians around the system and adjust the brightness of street lights according to road conditions to reduce unnecessary power waste. The system has a mature self-fault detection mechanism and is equipped with a wireless communication device for data exchange and timely communication with the host computer terminal. The intelligent street lamp system in this paper can be used to reduce the occurrence of pedestrian and vehicle accidents at intersections, and at the same time reduce the consumption of manpower and material resources for street lamp troubleshooting, to achieve energy conservation and emission reduction.

Keywords: Internet of Things; Early warning system; Intelligent transportation

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1. Introduction

China is a big traffic country, with the construction of smart cities and the continuous development of roads, street lighting facilities are also being used on a large scale, so street lights are of great significance for urban lighting and traffic safety. On the one hand, with the change of seasons, the length of the day will also change, and only relying on the time point to control the brightness and darkness of the lamp lacks accurate time series trend prediction, which will cause a waste of energy. On the other hand, although the smart street lamp system in some cities is also equipped with relevant fault detection, the diagnostic function is limited to the preliminary fault phenomenon, and there is no supporting related system. The staff needs to investigate the problem one by one, which is very time-consuming and laborious. Therefore, effective fault diagnosis and intelligent early warning play a vital role in ensuring the safe and stable operation of urban lighting systems. Based on the above phenomenon, we designed a street light warning system based on Internet of Things technology. The system will control the operation of street lights and detect faults through two sets of subsystems.

The system framework design consists of a main control system and an auxiliary control system. The main control system is used to monitor the running status of the street lamp, and at the same time upload the relevant light, current, and other parameters to achieve real-time control of the street lamp, and upload the data to the control terminal. Smart street lights detect vehicles and pedestrians through cameras and adjust their brightness in time according to road conditions to ensure sufficient visibility for pedestrians and vehicles.

The auxiliary control system, also known as the detection system, will monitor the operating status of the circuit and compare it with the set standard value, predict the future circuit operation trend through the circuit's current habits of deep learning, and report to the control terminal in time if a component of the circuit system is found or predicted to fail. The interface of the control terminal will display the location of the faulty street lamp and the faulty parts, and the maintenance personnel will achieve accurate repair through the content displayed by the terminal.

The two systems are loaded on the main control unit (MCU) at the same time, and the communication between the two systems and the host computer will be connected through the Internet of Things module. The IoT module adopts the ESP8266-01S Wi-Fi communication unit, which can withstand large data exchange and reduce communication delay. The Wi-Fi module communicates by sending heartbeat packets to the terminal server at regular intervals at the application layer to keep the connection alive and ensure the reliability of the communication [1].

Figure 1 is the overall structure of the intersection intelligent lighting system, which comprises: a light emitting diode (LED) lamp as the lighting unit, light dependent resistors (LDR) light sensor, and a passive infrared sensor (PIR) motion sensor as perception unit, Arduino microcontroller as system control unit, Wi-Fi module as wireless communication unit and signal transmission unit, power supply unit that provides energy for other units of the system. The overall structure of the system is as follows: LED lamp, Wi-Fi module, LDR light sensor, and PIR motion sensor are connected to the Arduino microcontroller while the power supply unit is connected to the LED lamp, LDR light sensor, PIR motion sensor, and Arduino microcontroller respectively. The single-chip microcomputer and the control terminal uses the Wi-Fi module as a bridge to ensure the smooth flow of information.

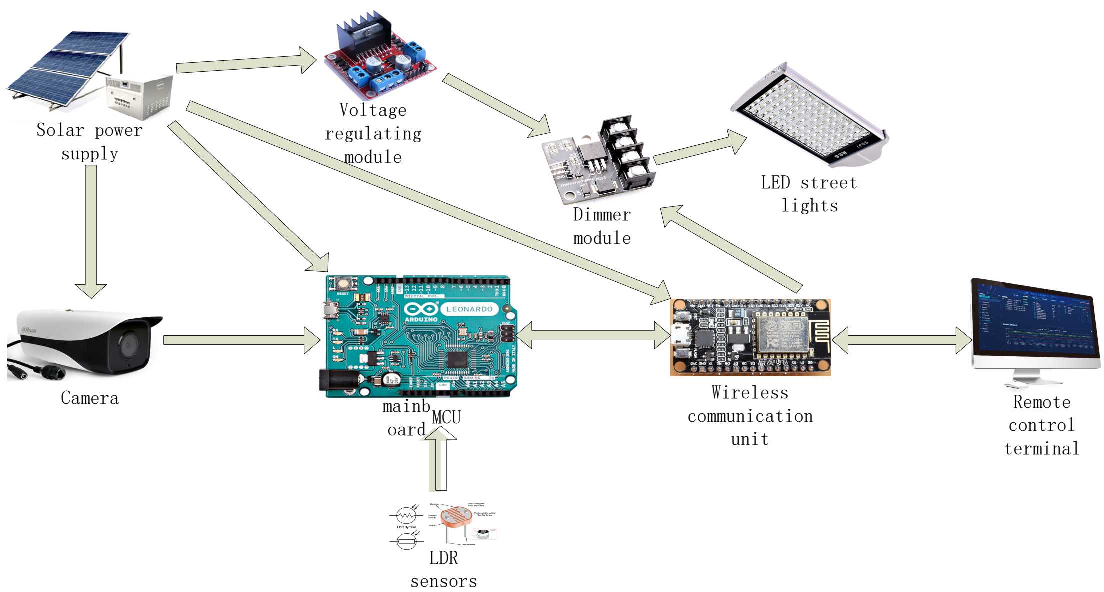

Figure 1. Structure of intelligent lighting system at an intersection

2. Method

2.1. Control unit to adjust the brightness of the lighting unit

When the light intensity is greater than the set threshold, the system obtains the light intensity information through the LDR sensor, and the control program will turn off the street lights to save energy. With the gradual weakening of the light intensity, the photosensitive resistance will gradually decrease, the current inside the sensor will gradually increase, and then the current signal will be converted into a digital signal through the filter. When the light intensity signal obtained by the system is less than the threshold, the street lighting will be started, and the lighting power will be adjusted through the following scheme:

(1) In the case that pedestrians or vehicles do not appear at the same time, the street lights run at low power and only have basic lighting functions to save energy.

(2) When pedestrians and vehicles appear at the same time, through the prediction of the road trajectory of the vehicle, the system will judge whether the vehicle and the pedestrian will collide, and adjust the intensity of the street light in time to remind the pedestrian and the vehicle to reduce the occurrence of traffic accidents.

2.2. Road user trajectory prediction based on deep learning

Combined with the state-of-the-art you only look once (YOLOv8) object detection algorithm and DeepSORT object tracking algorithm, the movement trajectory of a variety of common road users is predicted to quantify the degree of night risk at intersections. Video data is collected with a variety of road users (vehicles, pedestrians, and bicycles) and the target location and category in each frame of the image are labeled. Next, the pre-trained YOLOv8 model was used for object detection, and the video frames were input into the model and the detection results such as the position, category, and confidence level of the targets in each frame were obtained. Then, the target detected by YOLOv8 was used as the input of the DeepSORT target tracking algorithm, and the target was tracked by the combination of Kalman filter and depth feature representation, and a unique ID was assigned to each target, to obtain the trajectory information of the target, and the nonlinear regression model was used to predict the trajectory. Finally, object detection, object tracking, and motion trajectory prediction are continuously carried out in the video stream, and updated in real-time based on the latest data, to achieve real-time road user motion trajectory prediction and provide continuously updated prediction results.

2.3. Communication establishment based on TCP/IP protocol

The communication module of the system adopts transmission control protocol/internet protocol (TCP/IP), which is a connection-oriented communication protocol that ensures the reliability and orderliness of data transmission. Firstly, establish a network server to connect the communication module with the host computer terminal and the client, the client is the street lamp end, and the main control system and the auxiliary system will establish a database respectively by the detected results, send the data to be transmitted to the communication module in the form of data stream, and the communication module will package these data and send them to the host computer terminal for analysis, and intuitively visually present to the staff. The communication module, the host computer terminal, and the client ensure a smooth data transmission link by continuously sending data packets.

2.4. Fault detection and protection system

For the auxiliary self-test system, we convert the current of the street lamp from the current transformer into a small current signal, then convert it into a voltage signal again and process it by the Kalman filter algorithm, and then convert the electrical signal into a digital signal for the microprocessor to read. Considering the fluctuations of its working circuit, when the circuit current is set to be greater than 2 times the working current, it is considered that a short circuit occurs. When a short circuit occurs, the MCU of the motherboard sends a signal to the relay through the driving circuit and turns off the street light circuit for short-circuit protection.

When the street lamp is damaged, the single-chip microcomputer cannot detect the current signal or the value is too small, and it is judged to be broken. Regardless of whether there is a short circuit or an open circuit, the device will use the wireless communication unit to send relevant activity logs to the remote terminal to realize self-inspection of street lamp faults.

3. System hardware design

The intelligent early warning system uses the Arduino board as the main control MCU, and the Arduino supports a wealth of expansion modules, such as sensors, actuators, etc., with good compatibility and powerful data processing capabilities. The main control board will be directly connected to the LDR sensor and night vision camera through the serial port. The LDR sensor will provide light-sensing information to the motherboard in real time, and the night vision camera will provide the detected vehicle and pedestrian conditions. The MCU will automatically control the LEDs based on the implanted system program combined with the information obtained.

The communication module uses the ESP8266 microcontroller for real-time contact with the control terminal. The main control MCU will adopt a more accurate serial communication mode with the communication module, and the data transmission between the communication module and the terminal will be based on TCP/IP wireless communication. Data transmission is divided into reliable transmission and unreliable transmission. Generally, TCP/IP-based transmission is connection-oriented, reliable, and byte-stream transmission, while user datagram protocol (UDP) transmission is a non-connection-oriented, broadcast-oriented, and unreliable transmission mode. TCP/IP data transmission requires that the link is always connected. In terms of efficiency, UDP is more efficient than TCP/IP. In terms of security, TCP/IP is more secure. In recent years, most of the lighting control systems designed are TCP/IP communication where the control terminal communicates with the Wi-Fi module, and the application layer sends heartbeat packets at regular intervals to keep the connection alive and ensure the reliability of the communication.

4. System software design

The control terminal adopts a graphical operation interface to provide more intuitive data information and convenient control. According to the design requirements of the software and the characteristics and advantages of the current mainstream system development platform, LabVIEW programming software was finally selected to develop the lighting control software. The Lighting Control Software for Smart Lighting Systems developed based on LabVIEW is a multi-modular application designed to provide comprehensive lighting control functions and a user-friendly interface. Since personnel generally detect the operation status of each street lamp in real-time through the terminal system, it will be extremely important for the design of the control terminal system. Its main design is as follows:

4.1. Status interface

The status of each street lamp will be displayed in the status interface.

(1) Display the status information of all street lights in the form of a list or grid on the interface, which can include the street lamp number, location, etc., use icons or colors to indicate the status of street lights, with green indicating that it is on and red indicating that it is off, and at the same time providing a real-time refresh function to ensure the timeliness of the displayed status information.

(2) For each street lamp, a graph percentage will be used to represent the current brightness level to visually

show the change in brightness level.

4.2. Operation interface

In the operation interface, manual and automatic mode control will be displayed.

For the auto-adjustment function, the interface will display the current auto-adjustment mode, and automatically adjust according to the set ambient light intensity and road conditions. Each street light will be provided with an on/off button, allowing staff to manually control the street light on or off. After clicking the button, the system will immediately respond to the command and change the set brightness value to change the status of the street light, and update the status information on the interface in real-time.

4.3. Data analysis interface

(1) Display the statistics of street lamp usage: Display the average brightness of street lamps every day on the interface, in the form of a line chart, and users can choose to view the data on different days. The failure rate of each street lamp is presented in the form of a graph so that users can clearly understand which street lights have problems.

(2) Energy saving analysis: Showing the energy consumption of each street lamp and comparing the energy consumption of different street lamps can help staff find potential opportunities for energy saving. Based on the energy consumption statistics, the system can provide energy-saving recommendations, such as adjusting the brightness level, changing the opening time, etc., to reduce energy consumption. At the same time, the staff can see the effect of implementing the energy-saving recommendations, such as the reduction of energy use and cost savings.

4.4. Alarm function

In the design of the host computer template of the street lamp status warning system based on the Internet of Things technology, the alarm function is very important. It can help the staff to find and deal with the fault or abnormal situation of the street lamp in time. When the system detects a fault or abnormal condition of a street lamp, it can automatically trigger an alarm. Situations include street lights not turning on properly, abnormal brightness, communication interruptions, etc. The system will send an alarm message in a pop-up window, and the main contents are as follows:

(1) Alarm information content: Display the number and location of the street lamp that is faulty or abnormal, which can enable the staff to quickly locate the specific street lamp. Indicate the type of fault or anomaly, such as brightness anomaly, communication failure, etc. Record the time when the alarm occurred, so that the staff can understand the time when the fault occurred.

(2) Alarm processing: After receiving the alarm information, the staff can view the detailed information through the system interface and take corresponding measures, such as sending maintenance personnel to the scene to deal with it. The system supports real-time push of alarm information to relevant personnel, which can be notified by SMS, email, or applications.

(3) Alarm record: The system will record the details of each alarm, including the alarm time, the location of the street lamp, the type of fault, etc. Relevant personnel can view the historical alarm records in the system to understand the fault situation and treatment of the street lamp.

In this early warning system, the system can read the user's work data through various circuits and sensors, enable the corresponding program to control the lighting of the solar street lamp according to the data judgment, and upload the activity log to the remote terminal for recording through the communication program. For the communication module, the socket communication mechanism, MySQL database, and TCP/IP communication protocol are used. The specific process is that the street lamp sends a Synchronize (SYN) packet to the communication module, the server returns the corresponding Synchronize-Acknowledge (SYN-ACK) response and a new SYN package, and then the client returns the corresponding Acknowledge (ACK).

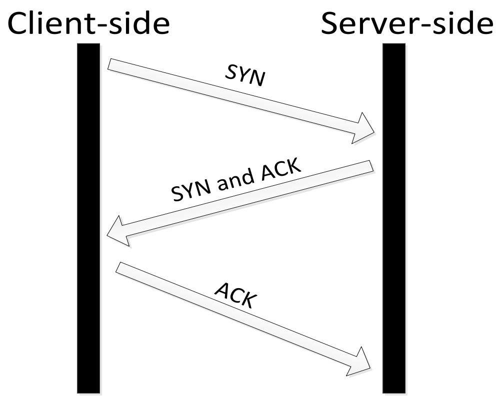

Figure 2. Connection established

SYN is the synchronization sequence number, which is the handshake information used by TCP/IP to establish a connection. ACK is an acknowledgment character, which is a transmission control character sent by the receiving station to the sending station in data communication. Indicates that the data sent has been acknowledged to have been received. In TCP/IP, if the receiver receives the data successfully, it will reply with an ACK message. Signals via ACK have their own fixed format, and length, and are replied to by the receiver to the sender [2].

When the first handshake and the connection are established, the client sends a SYN packet to the server and enters the SYN_SENT state, waiting for the server to acknowledge, where SYN is the synchronization sequence number. In the second handshake, the server receives the SYN packet and must confirm the customer's SYN, and at the same time sends a SYN packet, that is, the SYN-ACK packet, and the server enters the SYN_RECV state. In the third handshake, the client receives the SYN-ACK packet from the server and sends an acknowledgment packet ACK to the server.

The self-inspection program can timely and effectively determine whether the solar battery and street lamp head are faulty and can start corresponding measures to maintain and report the fault point for the fault, which is also convenient for maintenance personnel to carry out maintenance treatment [4].

5. Conclusion

In this paper, a street lamp status warning system based on Internet of Things technology is proposed, which connects the upper terminal and the main control MCU by using the communication module as a bridge and uses the TCP/IP protocol to ensure a smooth communication channel. The host computer will remotely monitor the operation status of the street lamp, obtain the fault situation and precise location of the street lamp in time, reduce the use of human and material resources for later maintenance, promote the development of the urban street lamp system to intelligence and energy saving, and help the dual carbon strategy. To sum up, compared with traditional street lights, the street lamp status warning system based on the Internet of Things technology designed in this paper has great advantages and good application prospects in many aspects.

Disclosure statement

The authors declare no conflict of interest.

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