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A Visual Management System for Online Monitoring of Street Lighting Based on Internet of Things

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Abstract

For street lighting system, real-time monitoring is considered as a crucial aspect for observing the stability and performance of the system. But due to the backward lighting control and administrative method, the precision of the existing methods is bad and the result of work is poor. In this research project, a remote visual monitoring system based on the Internet of Things is developed for online management of street lighting system. It solves the problems of real-time network transmission of monitoring system and loading slowly when loading a large number of street lamps by integrating technologies like WebGIS technology, GPRS and Zigbee wireless communication and webgl. Google maps and the multinational language library have been introduced to a user-friendly web-application, such that the monitored data are easily accessible via the Internet at home and abroad. The implementation process, including design and development of the hardware and software, is explained in detail. Field application result indicates that the system is flexible, extendable and fully adaptable to user needs, which offer high efficiency and considerable savings.

Keywords

Lighting System, Internet of Things, ZigBee, GPRS, Visualization

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1. Introduction

The streetlight, one of the massive and high-density urban infrastructures [1], is an important part of urban construction, and has great significance to perfect the urban functions, improve the quality of people's life and safeguard security of the urban environment. It is reported that lighting consumption in China is more than 421.6 billion kilowatt-hours per year; accounting for over 13% of electrical energy consumptions, with around 7-8% is urban lighting. The data reveal that municipal departments attach great importance to the implementation of urban lighting project in order to enhance the city's image [2]. However, along with the concepts of Intelligent City [3-4], Energy-Efficient [5-6] and Information Age being put forward and applied, the traditional street lamp monitoring system is faced with the following requirements and challenges.

1) The Lag of Information Collection and Unstable Transmission at The Terminal Acquisition Unit

The rapid increase multi-purpose lighting equipment leads to the monitoring data of street lamps is very large and these data are dispersed distribution. Because there is no effective system for detecting and gathering the information of terminal monitoring units, the perception and gathering of the terminal information have the problems of reflecting slowly and information transmission error, etc..

2) Visual Display and Real-time Monitoring of Terminal Equipment

Due to lighting monitoring unit has the characteristics of

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enormous amount, complex layout and apparent geographical location, it is necessary to provide some parameters of lighting equipment visually, such as the running status and space location, and offer the function of real-time monitoring and control in the running process[7]. Through the system platform, users can intuitively grasp the actual running of the lighting terminal equipment [8].

3) Backward Monitoring Method, not Flexible Control

In China, the traditional monitoring method usually includes clock control, photoelectric control and inductive control. By managing the streetlight intensively in manual or semi-automatic way, it is not in a position to realize the control of the single streetlight and flexibility of control. Currently, the technology of power line carrier communication and ZigBee wireless communication is used in the streetlight control engineering. In the last century, some companies in the United States have used power line carrier communication technology to build an intelligent control system of street lamps, which can be applied only to the short distance communication of line voltage stability and pure-signals [9]. Traditional power line carrier communication has the following disadvantages: With the increase of the distance, the signal becomes weak; the disturbance of work harmonic is serious; the load fluctuation and the noise are large and can't cross the transformer to complete communication. ZigBee, however, is a short distance and low power wireless communication technology, which have low power consumption and cost, large capacity, high transmission reliability and security. It overcomes the disadvantages of power line carrier communication and improves the reliability of street lamp monitoring system greatly [10]. And that’s why more and more universities and institutes apply GPRS [11-12] and ZigBee [13-14] to build street lamp monitoring system in China.

In the process of visualization, the method of the graph the database has been generally adopted, which could create the relationship between graphic and attribute in the Maplnfo or AutoCAD Map System Development Platform. Nevertheless, the complexity of the maintenance of this method blocked its large-scale application. Baidu electronic map, however, has many advantages including powerful features, friendly interface and clarify descriptions, which can meet the needs of the project from the perspective of function, openness and maintenance.

4) The Fault Alarm is Relatively Slow, and Lighting Cable Theft Occur Frequently

As the city expanding, the lighting project’s scale is extended rapidly as well. But at the same time, filched cable and severely damaged lighting facilities are being reported frequently. Simply relying on the customary road patrol is difficult to detect the running status of the street lamp.

The Internet of Things (IoT) [15-16] is a huge network combining the sensing technology and the Internet, which connects the upper software and the underlying devices, and enables administrators to access to the system status timely and accurately [17]. On the basis of existing research results and advanced technology, this paper puts forward a monitoring method visually based on the Internet of Things [18], and builds the C/S and B/S hybrid structure. The Intelligent Streetlight Management Platform is built from the following five aspects: (1) Using the core device (ballast) of the single lamp to collect the running data(current, voltage, power, etc.) of street lamp, while using the chip STM32F103ZET6(ARM), GPRS, ZigBee and peripheral circuits to build a local centralizing management device – Gateway. (2) Utilizing ZigBee [19], GPRS and Internet to construct the communication network in order to transmit running information of the remote street lamp efficiently. (3) Taking advantage of the processing platform of C/S terminal for fast analysis, storage of street lamps concurrent data uploaded by Gateway. (4) The B/S terminal used the Geographic Information System (GIS) [20] to achieve the visual monitoring and control. (5) Designing efficient and reasonable monitoring program and software program to realize the function of collecting information, transmitting data, etc..

2. The Layers Architecture

The visual monitoring system based on the C/S and B/S hybrid structure refers to import the Internet technology in the traditional monitoring system, and then achieves the mutual inductance and interconnection between the things and persons in the lighting system. In the B/S terminal, the GIS visualization technology is used to realize the connection among the real-time status of lighting fixture, the control operation and the visual layout of the monitoring unit. In the C/S terminal, the real-time communication connection is established by using the multi-thread technology to control gateway. By analysing the system requirements of building the layering architecture of the system, the model of urban road lighting management system based on the Internet of Things is indicated in Figure 1. The system can be subdivided into eight levels: Equipment Layer, Sensing Layer, Network Layer, Data Layer, Support Service Layer, Business Application Layer, Display Layer and User Layer.

2.1. Hardware Components of the Monitoring System

As shown in Figure 2, the system hardware architecture is mainly divided into three layers, the bottom layer is the data acquisition and control; the middle layer is the network communication; the top layer is the system monitoring centre. The system had an important role to play in distributed wireless remote measuring, remote signal acquiring, and remote controlling of the variable parameters, equipment status, etc.. The purpose of the design is to ensure the instant information, visualized operation and scientific management.

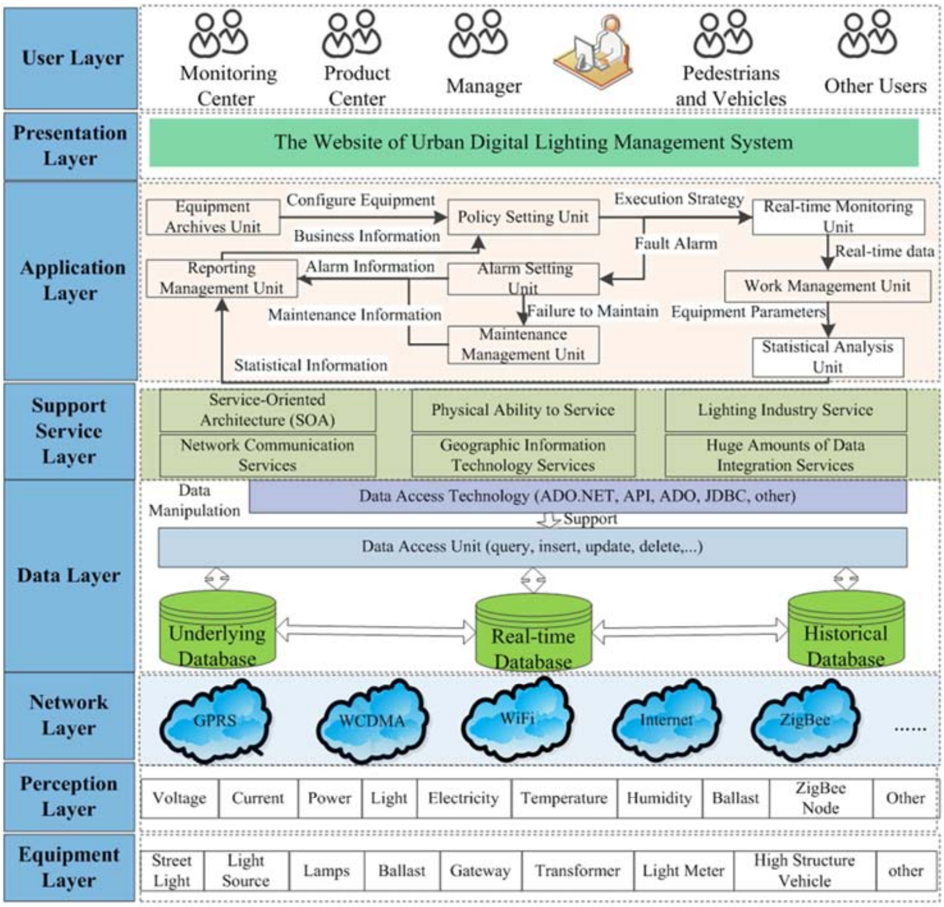

Figure 1. The model of urban road lighting management system based on the Internet of Things.

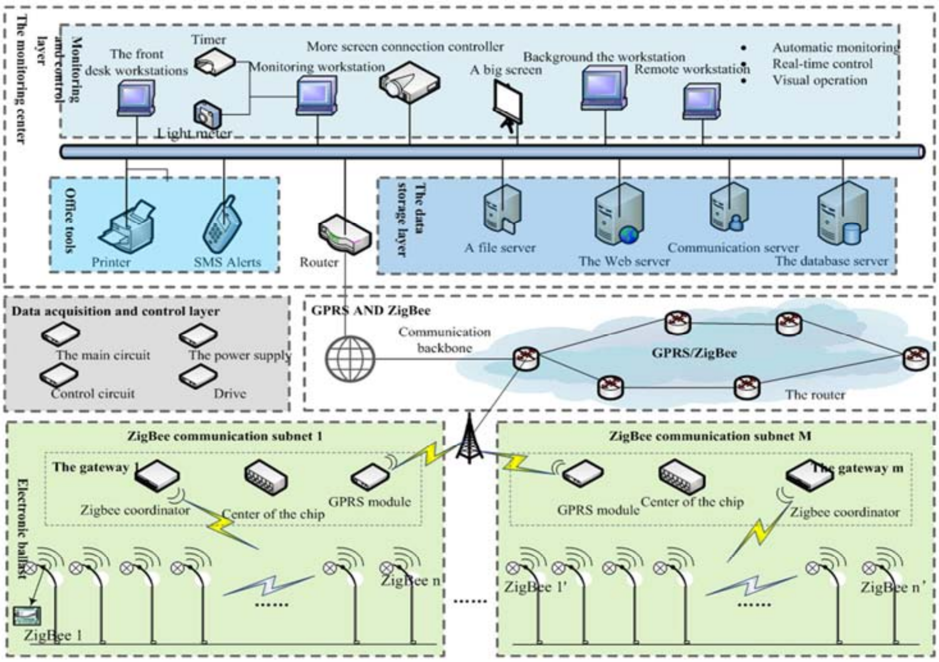

Figure 2. The hardware structure of the monitoring system.

2.2. Data Integration Scheme of Distributed System

According to the characteristic of scattering distribution of streetlight, the gateway is designed for dual characteristics of independence and controllability. Namely, the street lamp is connected to the nearby communication gateway with ZigBee network, which implementing the centralized and autonomous management for a single lamp. The gateway decided whether or not to upload the latest data based on the setting parameters of the system. Monitoring centre uses the B/S and C/S hybrid architecture. The former extracts and visualizes data information, the latter receives (send), processes data information. The system uses the database through the process to achieve data exchange and communication among each part. The data interface adapter, protocol conversion and heterogeneous network transmission technology are utilized to observe, collect and share the real-time data [21]. System database refers to the normal operation of the system and the management of all the data. The database architecture of monitoring and control system is illustrated in Figure 3.

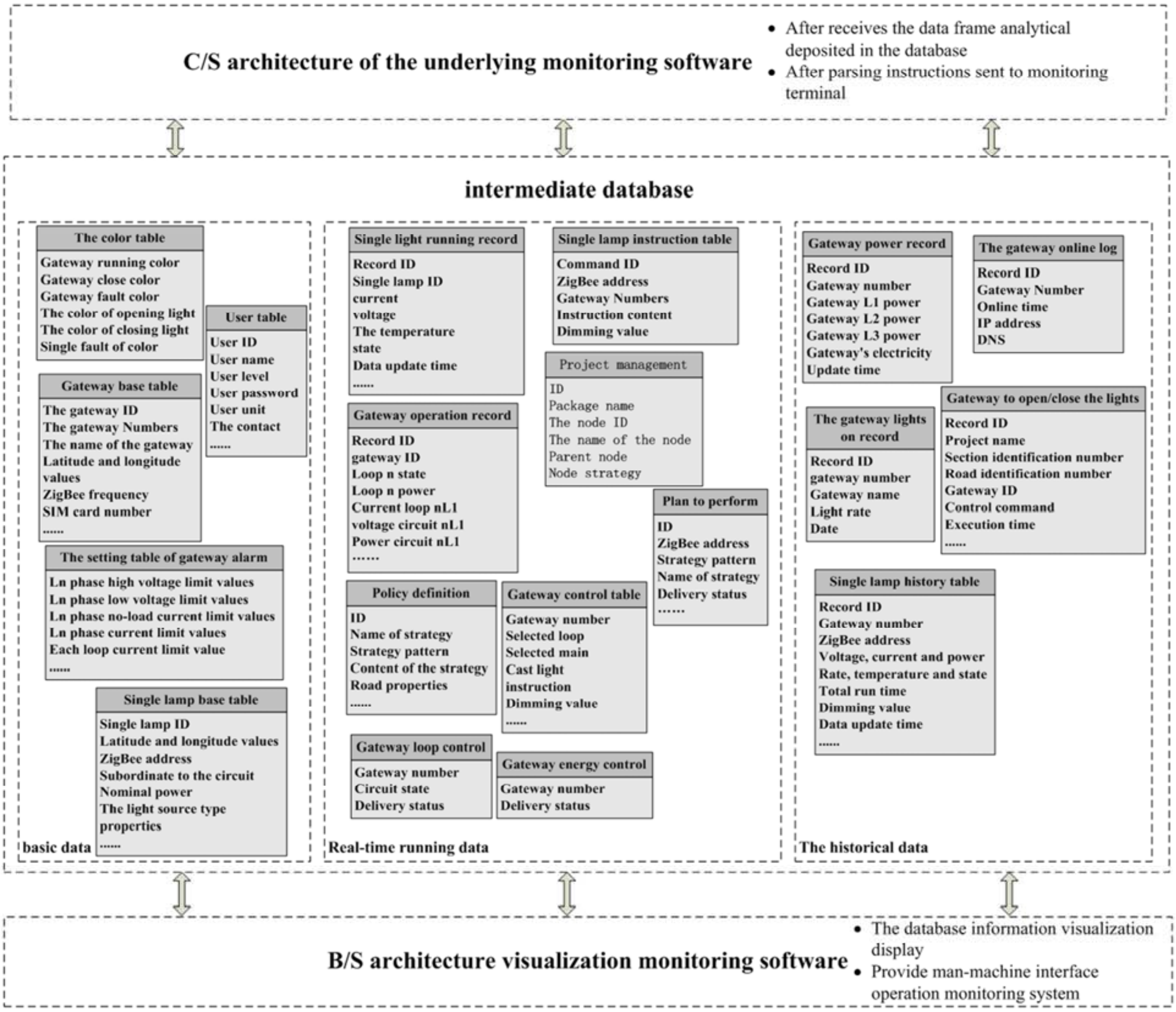

Figure 3. The database architecture of monitoring and control system.

2.3. Hierarchical Control of Distributed System

In this system, the street lamp is controlled by hierarchical mode, which mainly includes: system control, road control, gateway control, loop control, main/ auxiliary road control, cast light control and single lamp control [22]. Among them, loop control is defined by the distribution of the street lamp as indicated in Figure 4. Each loop of the gateway is connected with the AC relay as a switch. Through the connection between photoelectric couple and the microprocessor, it's easy to improve the security and anti-interference ability of the microprocessor, which can effectively prevent the large current of the circuit and reduce the cost of maintenance as well.

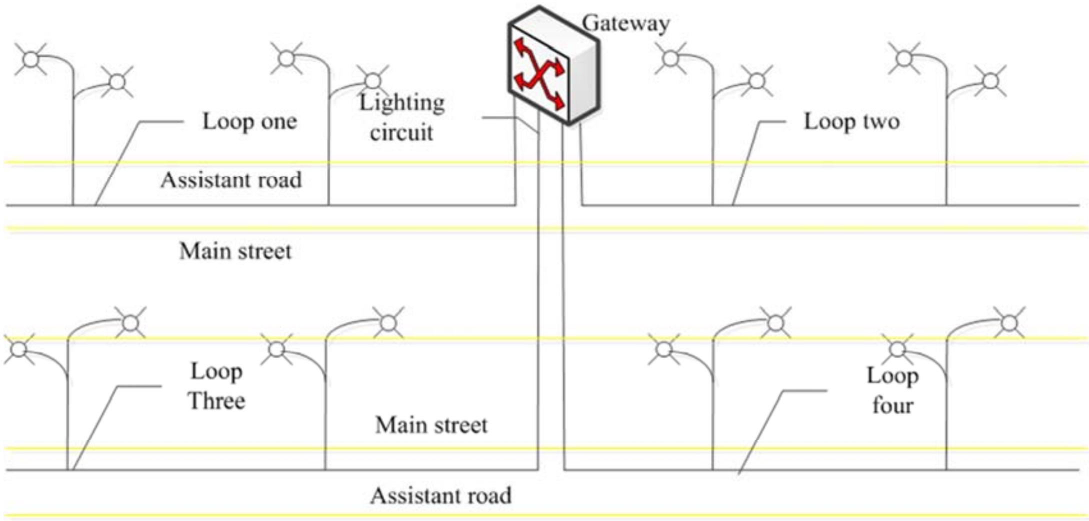

Figure 4. The distribution of control.

Hierarchical control system, controlled by opening/closing contactor or turning on/off ballast, uses logical attribute of single lamp stored in the database as the only index to rapidly detect changes from gateway to single-lamp controllers. With respect to system control and road control, the C/S will analyse the control instructions according to the logical record in the database, and then send the instructions to the specified gateway. The logic control of hierarchical system is indicated in Figure 5.

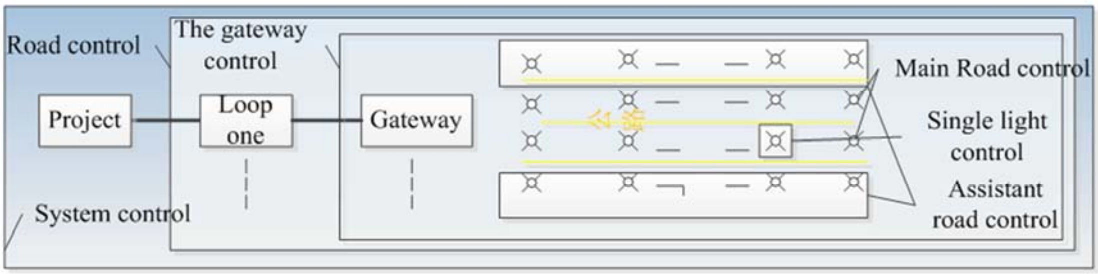

Figure 5. The logic control of hierarchical system.

3. Communication Network

3.1. Communication Network Architecture

The street lamps in the lighting system are distributed in the avenues and alleys of the city. In general, the system's data transmission with the street network is large while with a single lamp is little. With that in mind, the system is designed as a communication network, which combines long-distance and short-distance communication with remote control and road condition monitoring. In addition, taking account of reducing the cost, the structure of the communication network is designed as Figure 6.

From the perspective of communication, the system can be divided into ZigBee communication layer, GPRS communication layer and Internet communication layer. At the bottom of the lighting terminal of short-distance communication, ZigBee module is embedded in the gateway and the single lamp, which act as the coordinator node and the routing node. When the gateway is energized, a street lamp with the same channel and network identity will be added to the gateway to form a ZigBee communication network with a network topology [23-24]. The running data of each single lamp are collected by their single chip microcomputers. Then the data will be transmitted to the gateway through the ZigBee network. When the gateway receives the data, it will process, package and transmit the data to the monitoring centre server. In order to guarantee the reliability of communication, gateway and monitoring centre adopt the way of GPRS wireless data transmission based on TCP protocol. To ensure the stability of the connection of the GPRS network in normal communication, gateway sends the heartbeat package regularly to the server. If the server doesn't receive the heartbeat package after over limited time, it will be considered as a communication failure occurs, and the system would establish a new connection immediately.

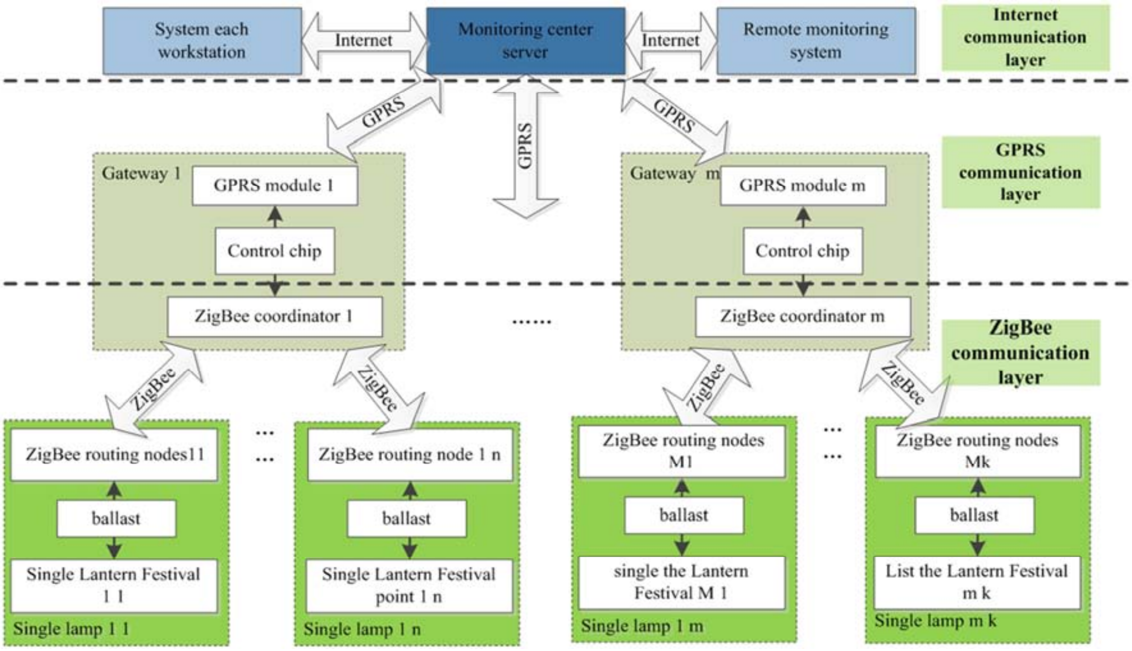

Figure 6. Communication network architecture.

3.2. Multi-thread Communication

The system uses an operation mode of multi-gateway to achieve independently control, and establishes the "long connection" to meet the real-time requirements of street lamp control. In order to ensure the upload speed of each gateway, the C/S side uses multi-thread technology for each gateway to allocate threads, which could be used to read the data and send the instruction. And the system uses a hybrid model, which increases the flexibility of usage and the possibility of serving more than one client at the same time. To make sure it's able to respond to all customers in time, the system adopts multi-thread technology to monitor the control instruction respectively. The multi-thread model is shown in Figure 7.

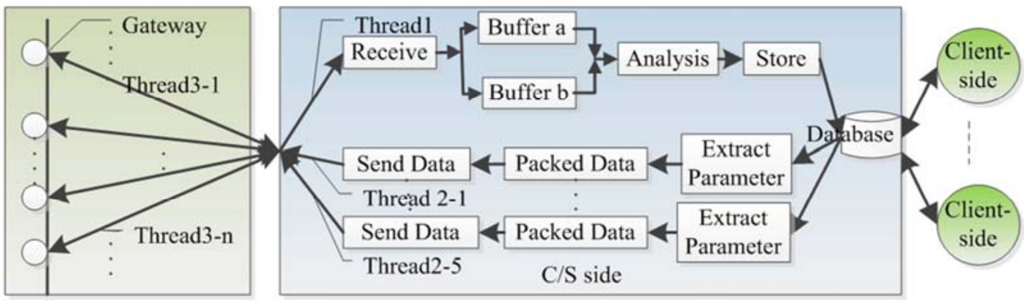

Figure 7. Multi-threaded model.

According to the characteristics of urban street lamps, the system will bear the pressure of receiving mass data of the street lamp in a short time. To avoid data loss, the system uses TCP/IP communication protocols and take advantage of the server's memory to save the data in the buffer a/b, and creates the thread 1 to alternately analyse and store the data in two buffers. This method will make extensive use of server memory resources and effectively prevent the phenomenon of "suspended animation" occurred in the process of analysing large volumes of data.

3.3. The Connection of Gateway

The gateway transmits an AT command to the GPRS module through the STM32F103ZET6 microprocessor, and establishes the data transmission link between the gateway and the server [25]. The experimental data in Figure 8 shows the connection between the gateway and the server, which are collected by the serial port debug assistant. Overall, the gateway is connected to the server, and then receives and executes the instructions of querying address, sending the frame of an address and uploading regularly heartbeat package.

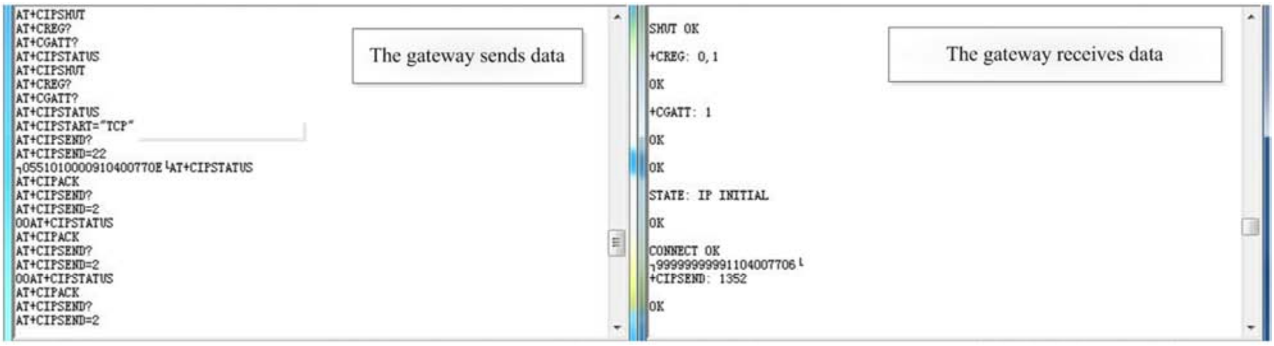

Figure 8. Data in the connection between the gateway and the sever.

When the gateway attaches to the server, the GPRS network abnormal interruption would cause the GSM module cannot receive the response instruction of "CLOSED" correctly and the AT+CIPSTATUS would remain connected. In this case, the data being sent to the server would be lost by this connection. To detect the phenomenon of 'virtual link' quickly, the server sends certain data to all gateways regularly. Therefore, an exception might occur if the gateway couldn't receive data from the server within the limited time, and then a reconnection to the server would be built.

3.4. Communication Protocol

To ensure the efficiency and real-time performance of the system, the specification of the communication protocol and the stability and reliability of the transmission mode are needed. Monitoring software for C/S mode uses multi-thread technology to handle data, and creates a number of data processing channels to realize concurrent process of the information flow. The above are presented in Figure 9.

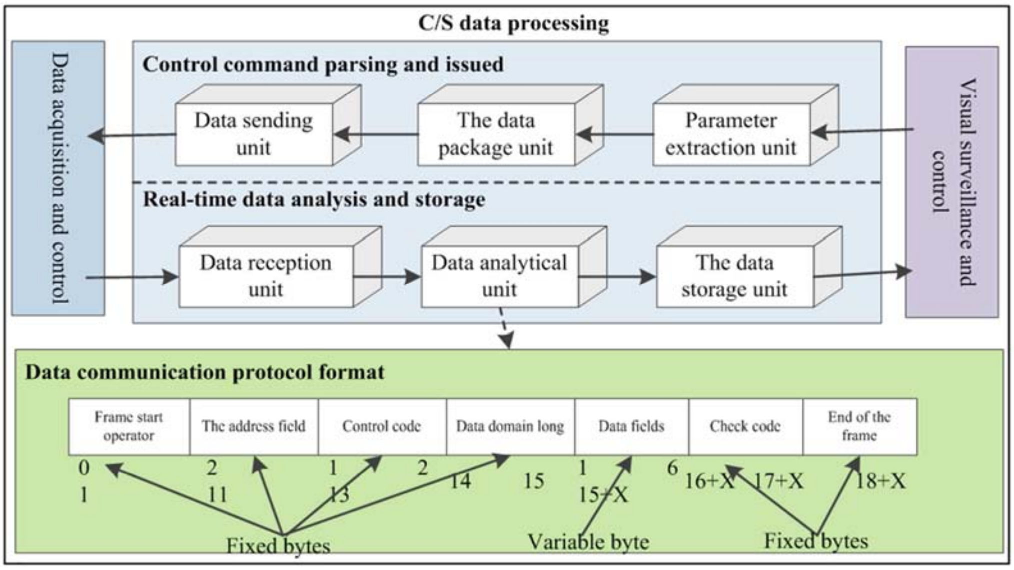

Figure 9. Communication protocol.

The information flow of the communication network of C/S terminal includes two processes: up and down. Upstream flow begins with the real-time operating data collected by the lighting terminal. To ensure the security of data and increase the reliability of communication, the data are packaged into a communication protocol frame, and encrypts by ASCII. In the upper computer, the data are first processed by the reception unit, and then become available for the data buffer. The character data which have been analysed are saved in the database and shared by the upper computer software. Conversely, the information flow of downstream experiences the reverse process: extracting parameters of operation instructions, packing data parameters and then sending to the gateway control unit.

Data analysis based on the data protocol format is shown in Figure 10. The binary data in the frame are designed as follows:

1) Starting Identifier

Represent the beginning of a frame of information;

2) Address Field

The sending address of the communication command, which is defined by Gateway address;

3) Control Code

The control code, which composes of two bytes, contains the information of the direction of transmission, abnormal sign and the code number. Through the code number, the system can identify the type of the data frame. Its composition is as follows:

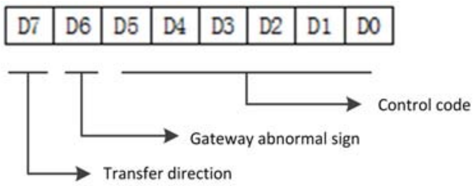

Figure 10. Data protocol format.

D7=0: The command frame send out from the master station, D7=1: The answering frame send out by the sub-station;

D6=0: Normal response, D6=1: Abnormal response;

D5-D0: Command number, such as "000001" and "000010" respectively express the instruction of "gateway parameter download" and "lamp parameter download";

4) The Length of Data Field

It is made up of 2 bytes;

5) Data Field

It includes the specific information of the communication. According to the different control instructions, its content is constantly changed;

6) Checksum

BCC XOR;

7) Frame end

0x03, the end of a frame of information.

4. Visual Monitoring and Control

4.1. System Function

Compared with data processing of C/S terminal, visual monitoring and control software for B/S terminal are mainly responsible for organizing of data structures and building application models. According to the plan of system development, the system function model is shown in Figure 11. The model is designed to meet the application requirements and ensure the realization of the system overall target. The system visual process consists of graphical management and data management, which are independent and unified. Graphical management refers to using the electronic map and graphic elements show the location of lighting terminal or facility layout vividly, including the elementary operation of the map display type, eagle eye view, navigation controls, drag and translation, zoom in and out, etc.. Data management is the core support of graphical visual display and operation, including the configuration of the basic parameters of the lighting terminal and the management of real-time running data of the lighting terminal. Graphical management is a shell of the system visualization, and data management is equal to the soul of the system. This combination eventually formed the optical monitor and control of the system which can be divided into eight modules: real-time monitor, equipment files, policy setting, alarm setting, maintenance and management, statistical analysis, user management and system help.

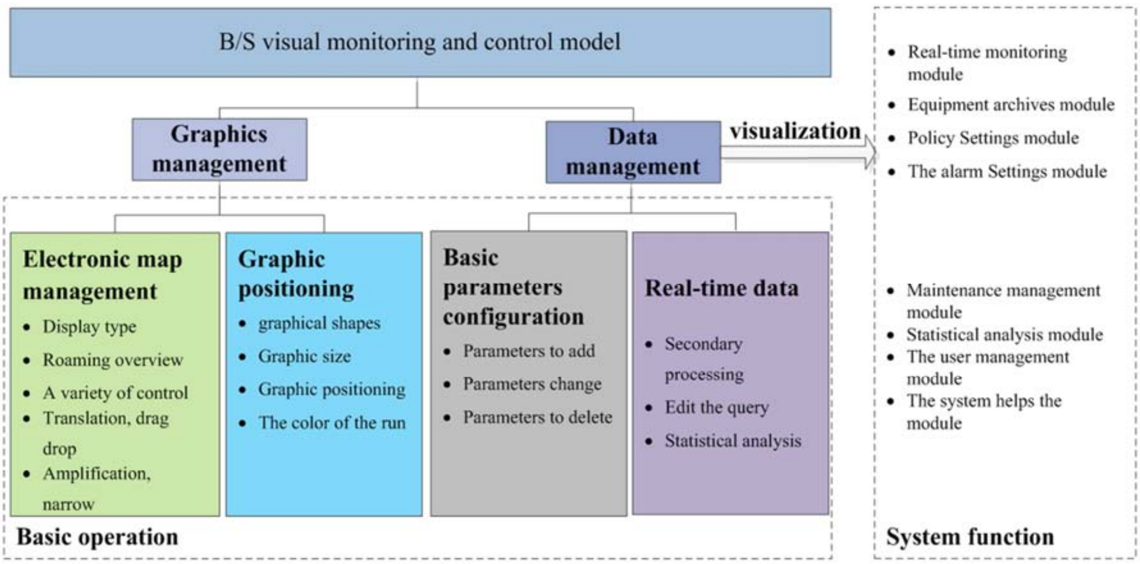

Figure 11. The model of visual monitor and control.

4.2. Visualization of GIS Applications

The visualization of lighting terminal equipment can not only improve the management efficiency and reduce the error rate, but also monitor and control the layout, location and operational status in real time. The system uses BMap API to call the Baidu map to achieve the terminal equipment visual monitoring. By analysing lighting device's characteristics, we have found that the number of gateways in the system is not much, but there are various kinds of parameters to display. The single lamp, however, have a little information to display, although its number has reached million levels. Therefore, the system utilizes the Marker class to define the gateway and the PointCollection class for street lamp. In addition, the size of the icon and the colour displayed can be changed by reconfiguring.

The graphical and data information of the system is stored in separate way, which can be established a link by the ID of the unique identity of the real-time monitoring unit to achieve related queries from graphics to property or from the property to the graph [26]. The system uses the gateway and the single lamp as the basic units of the monitoring, and puts the terminal parameter information received by the IOT into the database. Moreover, the graphics class provided by the Baidu map will draw monitor unit layout as showed in Figure 12. When the page is initialized, the system will send an application to the Baidu server to load the electronic map, and then read the monitoring unit parameter information from the system database and draw the monitor unit graphics on the map. When the page needs to be fully loaded, the system will start the real-time monitoring and the user can dynamically monitor the current operating parameters of the terminal device and control the running of the terminal equipment.

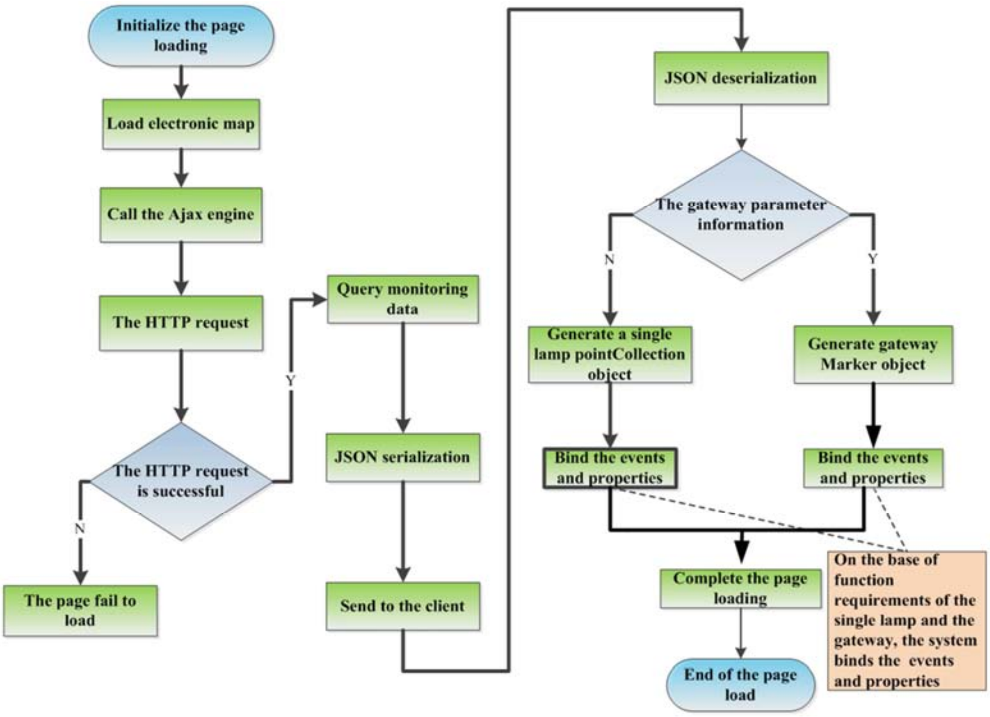

Figure 12. The flow chart of GIS visualization of design.

5. System Implementation

5.1. Real-Time Monitoring

The system uses Baidu map to achieve the visualization of geographic information, through the <script type="text/javascript"src="http://api.map.baidu.com/api?v=2.0&ak=key"> </script> statement to import Baidu map API and get the service provided by Baidu electronic map. By calling the Ajax engine to send an HTTP request to the server, the server will make a request to get the data of the gateway and the single lamp through the SQL statement. Then, the gateway will return the data to the client after the JSON serialization and deserialization.

The gateway and single lamp are represented respectively by a specific icon in the module. The former is a filled square while the latter is a solid circle. What's more, the gateway is associated with the data information through the gateway code, and the single lamp is associated with the specific data of the gateway code and ZigBee address [27]. In order to facilitate the users to view all of the device running conditions, the system uses different colours to represent specific running status, such as the blue indicates that the gateway works correctly, the black shows that the gateway is abnormal, the green represents the lamp works properly, the red indicates that the lamp communication fails and so on. Moreover, the power users can not only view the real-time running status of the gateway and a single lamp, but also control the gateway or the single lamp on the map, such as sending instructions of collection, turning on/off the light, dimming, etc..

5.2. Equipment Archives

Equipment archives manage a variety of equipment in this system, which utilizes onContextMenu event under the framework of jQuery EasyUI to achieve the function of editing, adding and deleting devices. This module used the addContextMenu() method provided by the map class API() to realize the function of adding a gateway and a single lamp. PointCollection and Marker object would enable the modify/delete function of the gateway and the single lamp. The system was designed based on the hierarchical structure of "project - area - road - gateway - single lamp", where deleting the root nodes or adding the leaf nodes was not allowed.

5.3. Policy Settings

Policy setting module is the function module of setting street lamp operating mode, which could be divided into 2 sub-modules, such as single street lamp module and Contactor module. The strategy definition of single lamp includes the timing adjustment strategy mode and the multi-fire lamp strategy mode, and the Contactor strategy is defined as the "sunrise and sunset times+ light intensity + time migration" switch module of Contactor. Scheme management is to select the appropriate strategy for different levels of nodes from the strategy definition, and then to generate a systematic plan. The user mainly uses the TreeGrid and DataGrid plug-in under the EasyUI jQuery library, and sends a request to the background by means of configuring URL property. After receiving the request, the background will use the SQL statement to access the database, and then the data will be serialized to JSON string and return to the front end so as to realize the data presentation.

5.4. Maintenance Management

In this module, there are three tabs: Emergency Maintenance, Routine Maintenance and Maintenance History. Emergency Maintenance includes five kinds of abnormal situations: gateway voltage is too high/ low, over current, no-load current, etc.. Routine Maintenance includes five types of abnormal situations, such as the battery power shortage, control cabinet water exceeded the limit, abnormal temperature, etc.. In the Maintenance History, the system recorded much information including maintenance type, maintenance time and so on, which is easy to query records. When you click on the left records, the abnormal gateway or single lamp would change the size of the icon for distinction.

5.5. Alarm Settings

Alarm setting module could transfer the terminal's fault automatically and ensure the running stability of the system. The object of alarm setting is the gateway which can monitor things may go wrong, and it's controllable, efficient and eases of maintenance. This module comprises two sub-modules of the alarm management and alarm mode. When an exception occurs, the gateway will send specific information of the fault to the server, and then the information will be translated and sent to preset-staff by mail or text messages.

5.6. Statistical Analysis

Statistical analysis is mainly used to display a large amount of data in the form of table or chart, which allows the user to easily understand and grasp the specific information about the project parameters. The module consists of five sub-modules, such as turning on/off time query, equipment running record query, electric quantity query, etc.. Since the HighCharts is on the base of the jQuery framework, it is required to import two JS files through the HTML <script> tag, which can initialize and access HighCharts. Thus, users can simply access to the exporting.js file to achieve the functions of chart export and printing.

The process can be illustrated as follows: First, using the Ajax method in the framework of the jQuery. Then, if a data request from the background server is made, the street lamp running data stored in the database will be packaged into a JSON string and return to the front page. Finally, the B/S side will complete the chart display after being analysed and processed by HighCharts.

6. Examples of Verification

6.1. System Data Flow Verification

There are various modules in the system, such as B/S side visualization software, SQL Server 2008 database, C/S side monitoring software and terminal lighting device, etc.. These modules are exchanging data and information all the time. The following operation could query the data of the single lamp to verify the system's data exchange. When the user clicks the query button of the 0001 address under the 0551020007 gateway in the B/S terminal, a query instruction of "Gateway ID +ZigBee address + content" was generated in the database. After detection of the C/S terminal monitor software, the instruction is packaged into 05510200070608B000000179 [2015-06-23, 20:59:53] and sent to the corresponding gateway through the GPRS network. At the same time the gateway sent data acquisition instruction 023030303130 363030303503 to the corresponding ballast through the ZigBee network. After receiving the instruction of the ballast, the answering data stream will be transmitted to the C/S terminal by the gateway, and the data stream (0551020007862AB00000010002227601170263026040491 E0D00006D7 [2015-06-23, 20:59:57]) is received and parsed by monitoring software. When the analysis result was saved in the database, the B/S side visual software will present the data in the real-time monitoring interface.

6.2. Receive and Transmit Ballast Data

Ballast uses the STM8S105 microcontroller as the core device, which has a full duplex asynchronous communication function. Besides, it includes a control circuit and data acquisition circuit which are mainly used to collect the street lamp voltage, lamp power, temperature and other information. Control circuit is primarily for controlling the ballast of the switch and light. Ballast switch is controlled by opening/closing the crowded bridge drive signal, and ballast dimming is by PWM (Width Modulation Pulse), so as to control the output power of the ballast [28].

6.3. Energy-Saving Effect of the System

The efficient and intelligent lighting management strategy plays an important role in reducing energy consumptions. As is shown in Table 1, from January 8, 2015 to January 22, 2015, the system stable operating data of the 593 lamps under the 8 gateways, each single lamp's electricity energy consumption is equally 2.77kW•h. Compared with the 3.5kW•h of each traditional lighting, every single lamp in the system has saved 0.73kW • h. The proportion of energy saving is 20.86%.

Table 1. The contrast of economy energy result on system.

Gateway Name	Number of single lamp	Cumulative power (kW • h)	The average daily energy consumption for per lamp (kW • h / day)
Jinggang Road	128	4590	2.56
Kaifu Road	76	2730	2.57
Zhenxing Road	95	3450	2.59
Tianfu Road	77	3395	3.15
Hugang Road	114	5060	3.17
Wenshui Road	39	1500	2.74
Jiaokou Road	33	1170	2.53
Xuexia Road	31	1140	2.63
Accumulation	593	23035	2.77
The raw data of traditional lighting			3.50

7. Conclusions

In this paper, a visual management system for online monitoring of street lighting based on Internet of Things is presented, combined to an intelligent management of the lamp posts derived by a control system switching on and off the light when necessary, increasing the lamps lifetime. The system is also equipped with web-based function which allows users to observe real time data of the monitored parameters, as well as the energy consumption.

Another advantage obtained by the control system is the data collected can also be used for fault detection. The system maintenance can be easily and efficiently planned by the messaging system in the website, allowing additional savings.

The proposed system is particularly suitable for street lighting in urban and rural areas where the traffic is low at given range of time. The independent nature of the power supply network allows implementing the system in remote areas where the classical installations are prohibitively expensive.

The simplicity of ZigBee and GPRS, the reliability of electronic components, the feature of the electrical map, the processing speed, the reduced costs and the ease of maintenance are the features that characterize the proposed system, which presents itself as an interesting engineering and commercial solution as the comparison with other technologies demonstrated.

Currently, it is inconvenient for construction workers to check the installation configuration of equipment because information of terminal equipment can only be viewed through the client browser. Therefore, a handheld terminal with an electronic map which can facilitate field monitoring and user's operation will be developed before long. Besides, it is possible to use the WIMAX standard where the GPRS is not provided [31-33]. Moreover, the materials presented here in this paper may serve as a guide for the intelligent management of remotely controlled loads and for smart grid and smart metering applications.

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