Abstract. A mass of data is collected into energy management system for the primary purpose of energy saving and emission reduction. The efficiency and accuracy of entire energy management system totally depends on the originality and instantaneity of the data acquisition system. Thus, the importance of data acquisition system in energy management system is self-evident. However, traditional manual meter reading method is not only time-consuming and inconvenient, but also lack of real-time. To solve this problem, this paper designs an energy consumption data acquisition system based on embedded system. The control center of this system is based on Raspberry Pi with embedded Linux operating system to manage the working process of this system including data acquisition, data analysis, data transmission and data storage. This paper mainly presents the hardware structure and the software design of the system. Actual energy consumption data of Beijing Government Affairs Service Center shows that the error rate of this system is less than 0.1% with low upload failure rate when the amount of acquisition point is more than one thousand. The system provides basic data on time for the monitor platform to do statistical and predictive analysis.

Introduction

According to “BP world energy statistical yearbook” in 2014, our country's energy consumption accounts for 23 percent of world, which indicates china has more energy consumption than any other country in the world. Because the public building is one of the most energy-consuming fields in china and the inevitable increasing trend of building energy consumption with the rapid process of urbanization, planning and monitoring the use of energy resource in this field is important to increase energy efficiency and save energy [1]. However, basic energy consumption data is incomplete and information share ratio is extremely low at present due to the lack of unified statistical method and the majority places still use traditional checking ammeter system, which is not conducive to make reasonable energy-saving standards. The data acquisition unit is the core part of the whole monitoring system because all operations are dependent on the data provided by this unit [2, 3]. Therefore, a reliability and real-timely intelligent data acquisition system is needed.

This paper uses a single board computer to design an intelligent energy consumption data acquisition system on the basis of serial communication and network communication. The design of the energy consumption data acquisition system shows many advantages over other systems. Firstly, the system has large storage spaces can store massive energy consumption data at least in one month, which would enhance reliability of the system. Secondly, the system gets analysis of energy consumption data accurately and efficiently. Finally, the design uses Raspberry Pi as control center which is a low-power device. The system will have a great effect on collecting all kinds of energy resources consumption data and improve real-time data monitoring and management efficiency.

The Overall System Architecture

The design is based on filed intelligent instruments which can be communicated through serial port. The system consists of a control centre and an application platform. The control center gets data from different kinds of measurement meters in buildings such as water-meter, ammeter, gas meter, heat.
meter. Then it analyses the data under the communication protocol and stores parsed data. Finally, the system sends data to manage platform through internet. The application platform can be understood as an interactive interface. It provides real-time data information through web browsers. The overall system architecture is shown in Fig. 1.

![Figure 1. The overall system architecture.](image1)

The system is set on Raspberry Pi Model B+ with an ARM1176JZF-S 700 MHz processor, Video Core IV GPU, and 512 megabytes of RAM. By plugging two high speed Universal Serial Bus (USB) to four Universal Asynchronous Receiver/Transmitter (UART) models into the USB hub of Raspberry Pi, eight expand serial ports are get used to connect with the field instruments. The on-board Ethernet port is used for network communication. The structure frame of the data collector is shown in Fig. 2.

![Figure 2. The structure frame of the system.](image2)

In consideration of this system works in strong electricity distribution room where electromagnetic interference and radiated interference exist, efficient anti-jamming measures are adopted in the design of this system to guarantee it run stably and reliably. From the design of hardware, the power signals are filtered and decoupled in powering circuits. Not only that, over-current protection circuit is designed in the board. The DC-DC isolated power supply module and transient suppressor diodes are adopted in RS485 circuit. Finally, the collector is installed in an almost closed metal box, which makes the system has better electromagnetic shielding property. The system in this paper has met the EMC requirements of the standard. Beyond above, raspberry built-in hardware watchdog makes it can back to normal working condition unattended if it crashes.
Design of the Data Application Platform

The data application platform is designed based on Browser/Server architecture. It integrates related information, which greatly improves the scalability and the stability of the system. The design separates energy consumption data acquisition system into control layer and application layer based on information security architecture. The application layer is responsible for managing related configuration information and showing energy consumption data and the control layer is responsible for energy consumption data processing.

The application web server is developed based on tornado which is a full-stack web framework and asynchronous network library written by python and the front-page is based on Ext Js5 which has rich and beautiful components and layouts and is supported by almost all of the popular browsers that greatly to shorten the development cycle. It provides energy consumption information service to authorized users in any time and any place with a browser.

The web server achieves this function: showing real-time data, configuring time and IP address of data collector system, configuring location information, setting the serial port parameters (baud rate, data bit, parity bit and stop bit) used to communicate with meters, setting the TCP communication parameters used to communicate with data center and acquisition points information.

Software Design of the System

Collecting Data and Parsing Data

The collector communicates with measurement meters through RS485 interfaces based on half-duplex communication having the advantages of simple structure, low cost, convenient connection with field instruments. The communication protocols of meters are MODBUS-RTU protocol and DL/T645-1997 protocol. They are all master-slave application-level protocols. That is, it is independent of the type of underlying network supporting communication between a host and set of slave devices. In energy consumption data collection system, the collector is host and the meters are slave devices which are set unique identification. All slave devices will receive the steering order send by the host, but only the designated slaver will response. The command frame format of the two protocols is shown in Table 1 and Table 2.

Table 1. The command frame format of DL/T645-1997 protocol.

| Description | Initial flag | Address fields | Initial flag | Control code | Packet length fields | Data fields | Checksum | End flag |
|-------------|--------------|----------------|--------------|--------------|---------------------|-------------|----------|---------|
| Code        | 68H          | A0~A5          | 68H          | C            | L                   | DATA        | CS       | 16H     |

Table 2. The packet format of MODBUS-RTU.

| Address code | Function code | Data fields | CRC checksum |
|--------------|---------------|-------------|--------------|
| 8-Bits       | 8-Bits        | 8xN-Bits    | 8-Bits       |

The system designed in this paper supports data acquisition based on command from control center and actively timing acquisition. The cycle can be set from ten minutes to one hour and the system can communicate with at least 32 different measurement devices simultaneously.

The flow chart of acquisition program is shown in Fig.3. The main part of the program contains eight serial data collection, storage and processing threads and one data transfer thread. At the beginning of one serial communication thread, the program reads configuration information of all points which will be acquired through this interface from MySQL database. Then makes up command frame according to communication protocol and send the command. It’s important to note that the multiple meters connected in series should have the same protocol.

After receiving the replay from the slaver, the host parses message and get valid data and write it to database. In addition to, the program may make a simple calculation to process some data, which is usually to get the sum of all acquired instrument data on one serial interface or extraneous data from...
some aggregate. Now, the data acquisition of one point has been done and the program enters a while loop getting data one by one. To ensure serial interfaces normal work during the system collecting data, a timeout is set up. If the host can’t receive response within the specified timeout period, it resends the steering order. And if the acquisition fails three times in succession, it is determined that the point has physical trouble, and the host abandons its acquisition.

![Flow chart of acquisition program.](image)

**Figure 3.** The flow chart of acquisition program.

**Transmitting Data**

According to the relevant standards and guidelines in China, the process of communication between the collector and the upper computer is shown in Fig.4. This system uses TCP protocol at the transport layer to send message. In this process, the data center as TCP server to monitor information and the collector as client to send connection requests when it wants to open a connection. The MD5 message digest algorithm is used in authenticating process. After both sides establish a TCP connection, neither side can initiate to terminate it and the client need to send a heartbeat message regularly to inspect network connection. Once the connection breaks, reestablish the connection immediately. If client has been authenticated, then it will receive some configuration parameters from the server and uploads the encrypted data packets to server proactively. During the period of uploading, the failed data packets due to network congestion or server crash are stored in the SD card and resent after the TCP connection recovers.

The application layer packets are encapsulated in XML format and sent in text format. All packages include building code and collector code. When energy consumption data packed, classification or itemization code, acquisition time and data value are included. Besides, the total number of packets about to upload and the current package number are included if it is a break point resume packet.

To ensure the the security of information through internet, all communication packets are encrypted by using AES-128-CBC algorithm. The encryption key and initialization vector(IV) [4-6] is stored in local with hex encoding. The code implementation of encryption and decryption uses cryptor module.
Data collector send a TCP collection request

Begin

Connect successfully?

No

Valid Connection?

Send a heartbeat packet

No

Invalid Connection?

To authenticate

Yes

Successfully?

Set the configuration

Data collecting and processing

Data storage

Data transmission

Successful?

No

Yes

End

Figure 4. The process of communication between the collector and the upper computer.

Analysis of the Results

In order to test whether the energy consumption data acquisition system based on Raspberry Pi can accurately calculate energy consumption information and send information to data center in real time, we use the data get from the display screen of intelligent instruments in building as a contrast. Data used in this paper comes from energy control project in Beijing government affairs service center building. The model of field three-phase electric energy meter is EM160. The serial port parameters are as follows: baud rate is 2400, data bit is 8, parity bit is None and stop bit is 1.0. In terms of the system calculation accuracy, error within 0.1% is acceptable. The results are shown in Table 3.

Table 3. Comparison between display value and the system.

| Type                                | Display value | Calculate value | Error  |
|-------------------------------------|---------------|-----------------|--------|
| A Phase voltage(V)                  | 230.80        | 231.0005        | 0.087% |
| A Phase current(A)                  | 1.12          | 1.1202          | 0.071% |
| A Phase active power(KW)            | 0.18          | 0.1805          | 0.018% |
| Instantaneous active power(KW)      | 0.18          | 0.1799          | 0.056% |
| A Phase reactive power(KVAR)        | 80.19         | 80.1926         | 0.003% |
| Instantaneous apparent power(KVAR)  | 80.18         | 80.1743         | 0.007% |
| A Phase power factor                | 0.71          | 0.7102          | 0.028% |
| Forward total active power(KWH)     | 1976.78       | 1976.7965       | 0.0008%|
| Reverse total active power(KWH)     | 0.00          | 0.0000          | 0.000% |
| Forward total reactive power(KWH)   | 0.02          | 0.0200          | 0.000% |
| Reverse total reactive power(KWH)   | 1881.54       | 1881.5324       | 0.0004%|

In addition to that, a serial of performance tests had done to test whether the energy consumption data acquisition system can work stability. The acquisition cycle and upload cycle are set to 15
minutes and the amount of acquisition point is 1000. We calculate the acquisition success rate and upload the success rate once every other month for 3 months. The results are shown in Table 4.

Table 4. The results of performance test.

| Time  | Collecting times | Acquisition success rate | Upload success rate |
|-------|------------------|--------------------------|---------------------|
| May   | 2976000          | 99.7245%                 | 99.6167%            |
| June  | 2880000          | 99.7734%                 | 99.7628%            |
| July  | 2976000          | 99.5532%                 | 99.6957%            |

Conclusions

The energy consumption data collector designed in this paper supports data acquisition, data analysis and storage, data transfer and different communication protocols. The software is designed according to the requirement analysis described in the “Technical guidelines for energy consumption monitoring system of government office buildings and large public buildings” so that the system can work with any host computer. It has been put into use in the buildings of Beijing Government Affairs Service Center as part of energy consumption monitoring platform. The results show that the system is reliable and effective. The data analysts can take scientific countermeasures based on this system. The system can totally replace the traditional method because of its low cost and low power consumption. So the energy consumption data acquisition system is of a great significance for the design of energy monitoring system.

References

[1] Liang Zhao, Ji-li Zhang, Ruo-bing Liang, Building Science. 29 (2013) 49-52. (In Chinese)
[2] Bo Tang, Li Peng, Shuang-shuang Wu, Computer engineering & Software. 35 (2014) 150-156. (In Chinese)
[3] Xiao-li Wang, Yue Yu, Journal of Jilin Jianzhu University. 32 (2015) 69-72. (In Chinese)
[4] Guo-shun Wang, Yan Zhang, Advanced Materials Research. 472-475 (2012) 1804-1808.
[5] Yahya, A.A, Abdalla, A.M, Proceedings of the 2009 International Conference on Security & Management. (2009) 113-116.
[6] Yi-Shiung Yeh, Ting-Yu Huang, Han-Yu Lin, Journal of Information Science and Engineering. 25 (2009) 937-944.
[7] Jing-dong Ren, Xiang-hai Meng, Chun-ming Xu, Petroleum Science. 9 (2012) 100-105. (In Chinese)
[8] Yong Wu, Jing Hou, Ke-xi Xu, Building Science. 31 (2015) 1-14. (In Chinese)
[9] Yi-Ting Kang, Cao Yong, Su Hua, Journal of Central South University (Science and Technology). 43 (2012) 146-150. (In Chinese)
[10] Wei Fu, Jian Fang, Process Automation Instrumentation. 34 (2013) 49-53. (In Chinese)