Intelligent monitoring system for thermal energy consumption of buildings under the IoT technology

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Abstract: In view of the poor accuracy of single value of heat energy consumption and the weak real-time monitoring of energy consumption in buildings, an intelligent monitoring system for thermal energy consumption of buildings under the internet of things (IoT) technology is designed. The overall structure of the intelligent monitoring system for thermal energy consumption of buildings is constructed. The DSP integrated signal processor is used for data acquisition and real-time information processing of thermal energy of buildings. A wireless intelligent gateway for building thermal energy consumption monitoring is designed by using internet of things technology, a wireless sensor network model is constructed. The VME bus is used as information transmission channel to realise intelligent monitoring for thermal energy consumption. The test results show that the real-time monitoring accuracy of the system is better than that of the traditional method and it has a good application prospect in all aspects.

Keywords: internet of things technology; IoT technology; thermal energy of buildings; energy consumption monitoring; system design.

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1 Introduction

Targeted on the fact that the current method ignores the real-time acquisition and data conversion of thermal radiation information, resulting in poor accuracy of the thermal energy consumption monitoring of buildings and weak real-time energy consumption monitoring. The design of intelligent monitoring system for thermal energy consumption of buildings is based on the real-time information acquisition and data integration processing of energy management data (Huang and Liu, 2016). Combined with the construction of user interface layer, application layer and data layer, the wireless sensor network and internet of things (IoT) technology is used to build the database and network system for thermal energy consumption monitoring of buildings. Combined with property management services, energy-consuming website services and short-message services, the intelligent monitoring for thermal energy consumption of buildings is realised (Sun et al., 2014; Lin, 2009). Literature Rong et al. (2013) proposes a design method for the thermal energy consumption monitoring system of buildings based on B/S mode and SOA architecture. The manual carrying sample collection equipment is used to sample and evaluate the on-site thermal energy consumption and the bus transmission control of the thermal energy consumption monitoring system of buildings is carried out in the B/S mode. The integration of the system is not good and the real-time monitoring of the thermal energy consumption of buildings is not good. Literature He et al. (2011) proposes a software development technology for thermal energy consumption monitoring system of buildings based on SOA architecture. The system is mainly composed of bus transmission control module, human-computer interaction module and sensor module. It uses manual sample collection equipment to sample and evaluate the on-site thermal energy consumption and constitutes a network through self-organising method to realise energy consumption monitoring of thermal energy of buildings. The system has poor real-time recall for energy consumption monitoring data. Literature Qi et al. (2015) proposes a design scheme for thermal energy consumption intelligent monitoring system of buildings based on wireless sensor network, which designs network adaptation layer, basic software layer and manual sample collection equipment to carry out sampling and evaluation for on-site thermal energy consumption. By combining the development layer, it conducts the network design for the thermal energy consumption intelligent monitoring system of buildings to improve the intelligence of the energy consumption monitoring of buildings. However, the complexity of the system design is high and the integration of hardware design is not good.

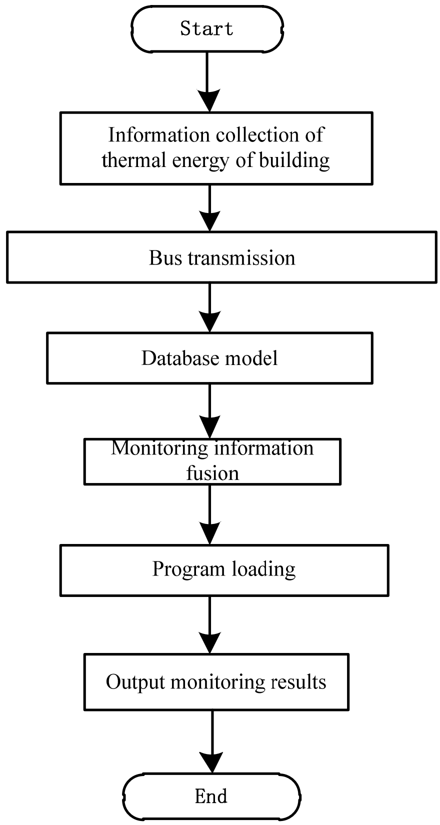
In the above traditional methods, the manual carrying sample collection equipment is used to sample and evaluate the on-site thermal energy consumption, which cannot complete the intelligent real-time monitoring for the thermal energy consumption of buildings. So the accuracy of the thermal energy consumption monitoring of buildings is poor and the real-time performance of energy consumption monitoring is weak. In view of the above problems, this paper proposes a design scheme for intelligent monitoring system of the thermal energy consumption of buildings under the IoT technology. This method has strong generality and flexibility for digital signal processing. The size of DSP chip is small and the operation speed is very fast. High precision, convenient interface, especially suitable for the complex digital signal processing algorithm in this paper. Firstly, the overall design of the system is carried out and the overall structure model of the building thermal energy consumption detection system is established. Then, the hardware of the system is developed and designed and the embedded building energy consumption monitoring platform system based on the B/S mode is constructed. And set up a special building energy consumption data acquisition device. The core control module of building thermal energy consumption monitoring system is constructed by embedded Linux system and the control program is loaded. Finally, the simulation experiments are carried out to compare the accuracy and real-time of the proposed method and the traditional method. The superior performance of the building thermal energy consumption monitoring system designed in this paper is verified.

2 Overall design and construction of the system

2.1 Principles and overall structure analysis of thermal energy consumption monitoring of buildings

In order to realise the thermal energy consumption monitoring of buildings, the overall structure model of thermal energy consumption monitoring system of buildings should firstly be constructed. The thermal energy consumption management information model is used to sample the whole process information of the thermal energy expenditure and the RFID technology and multi-mode VIX bus technology are used to sample the monitoring information of the thermal energy consumption of buildings. The collected data are integrated and processed to carry out the software development and hardware design of thermal energy consumption monitoring system of buildings (Shivam et al., 2008). Embedded ARM addressing technology is used for bus scheduling of large data information of thermal energy consumption monitoring of buildings, the design of control module and embedded software. The IoT technology and SOA architecture technology are used for the monitoring of buildings' thermal energy consumption and real-time measurement of energy expenditure. The thermal energy consumption monitoring of buildings is built on a general computer platform to carry out the information management and database construction of buildings' thermal energy consumption monitoring on different operating systems. In order to improve the compatibility and implementation of the thermal energy consumption monitoring system of buildings, it is necessary to install the Linux system in it and conduct buildings' thermal energy consumption monitoring and output power test in the IoT environment (Cooper et al., 2010). According to the above analysis, the flow chart of design principle for the thermal energy consumption monitoring system of buildings designed in this paper is achieved as shown in Figure 1.

Figure 1 Flow chart of design principle for the thermal energy consumption monitoring system of buildings



2.2 Development environment description and functional component analysis

According to the overall design and structure of the thermal energy consumption monitoring system of buildings shown in Figure 1, the functional module components are analysed and introduced. This paper proposes a design method for the thermal energy consumption monitoring system of buildings based on the IoT technology architecture. The system functional structure includes the information acquisition module of thermal energy of buildings, the integrated control module and the energy consumption detection module, IoT module and the human-machine interface module, etc. The resource scheduling model of buildings' thermal energy consumption monitoring is transplanted into B/S mode and SOA architecture platform under embedded Linux kernel to realise the software design and development of thermal energy consumption monitoring system of buildings. The database of thermal energy consumption monitoring of buildings is based on MS SQL Server 2000 of Microsoft Corporation and Microsoft SQL Server can provide the database services required for very large systems (Zhang et al., 2012). The IoT system of the thermal energy consumption monitoring system of buildings is divided into four layers: the user interface layer, the application layer, the data layer and the network layer (Yang et al., 2007):

1 User interface layer. The user interface layer is the object-oriented layer of the entire buildings' thermal energy consumption monitoring system of the IoT system. It provides user interaction services and offers real-time monitoring information of buildings' thermal energy consumption for property personnel, system administrators, building owners and the public. It also inputs the energy consumption monitoring data collected by the energy consumption monitoring sensors of each building into the information processing centre through the Internet (the network set up by the public users and the central server) to realise the intelligent monitoring and real-time information processing of thermal energy consumption of buildings.

2 Application layer. Data acquisition sensors are installed in the application layer of the IoT system and different database tables are used to store the basic information database of buildings. Heat meters are used to measure and display the information of heat released or absorbed by water flowing through the heat exchange system. The interface form can be RS485 or wireless interface (Gu et al., 2011).

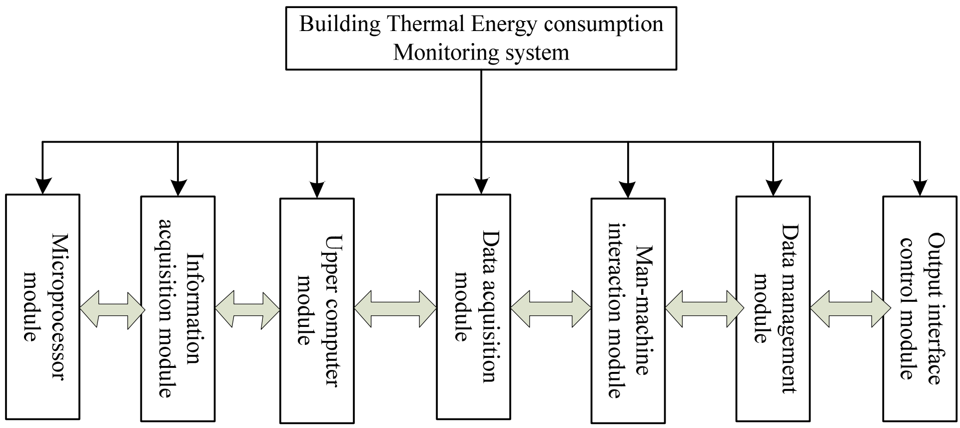
3 Data layer. In the data layer of the IoT system, the energy meter is used for data collection and real-time information processing of energy consumption monitoring. The energy meter should have the function of remote data transmission and at least have serial electrical interface conforming to RS485 standard. The data acquisition system of the thermal energy consumption monitoring of buildings includes the microprocessor, I/O interface, human-machine interface and communication interface to support upper computer or data integration processing.

4 Network layer. The network layer realises the network transmission control of the upper computer communication and energy consumption data through the IoT and performs integrated design and information encryption processing on the data packet before data transmission. The Register-Based Device with complete 32-bit VME bus architecture is used to realise the network output control of the thermal energy consumption monitoring of buildings and improve the online monitoring performance of the thermal energy consumption of buildings (Mao et al., 2016).

In conclusion, the functional structure for the thermal energy consumption monitoring system designed of buildings in this paper is achieved as shown in Figure 2.

The functions of each module are as follows: Microprocessor module can complete the operation of fetching instructions, executing instructions and exchanging information with external memory and logic components; The information acquisition module is to collect the information in the microprocessor and convert it into data; Upper computer module is mainly to achieve the acquisition of various analogue signals, AD conversion, numerical operation and transmission; Data acquisition module is mainly to achieve the acquisition of various analogue signals, AD conversion, numerical operation and transmission; Human-computer interaction module refers to human-computer interaction processing, which refers to the participation of people in the process of computer online data processing; The data management module uses the system hardware and software technology to collect, store, process and apply the data effectively; The output interface control module refers to when the internal circuit outputs a digital signal, current flows through, relay coils have current and then open and close, providing load conduction current and voltage; When the internal circuit outputs the digital signal 0, there is no current flowing through, the relay coil has no current and then the contact is often opened to disconnect the load current or voltage, in other words, the internal digital circuit is transformed into a signal through the output interface circuit to cause the load to move or not to act.

Figure 2 Functional structure module for the thermal energy consumption monitoring system of buildings (see online version for colours)

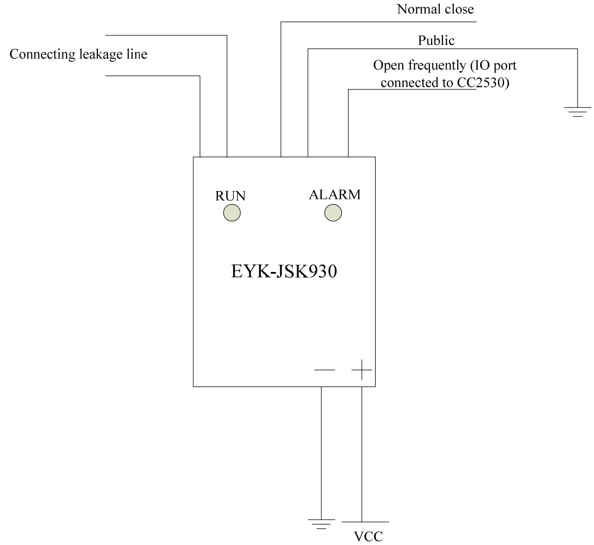


3 Hardware development and design of the system

3.1 Selection of core and peripheral devices

In the big data information processing process of the thermal energy consumption monitoring system of buildings, the thermal energy information collection and the IoT design of the buildings' thermal energy consumption monitoring are carried out by scheduling device drivers and the information encryption of the thermal energy consumption monitoring is performed by using the AES encryption and the MD5 identity authentication mechanism. The building energy consumption status is recorded in real time during the scheduling of thermal energy monitoring information of buildings. The embedded platform system for buildings' thermal energy consumption monitoring is constructed based on the B/S mode and the specialised device for collecting buildings' energy consumption data and processing information is used to conduct the adaptive scheduling of the buildings' energy consumption monitoring information in the local database (Luo and Yang, 2016), which is transplanted to the cloud computing platform by adopting the program-driven module to carry out the clock sampling and filtering of buildings' thermal energy consumption monitoring information and provide data input basis for the design of buildings' thermal energy consumption monitoring system (Chen et al., 2017). The timing collection period can be flexibly configured (adjustable from 5 minutes to 1 hour) and the information is debugged in the receiving module and the transmitting module. The integrated information processing module of the buildings' thermal energy consumption monitoring system is mainly composed of a DSP module, a PCI module and a bus transmission module. Using VisualDSP++ integrated compilation mode, the subprogram is compiled and installed according to the output energy consumption data of I/O interface and human-machine interface. The core controller is used for integrated DSP control of real-time information of buildings' thermal energy consumption (Zhang et al., 2016). The magnification of real-time information of buildings' thermal energy consumption is 120 KW and the A/D and D/A resolutions of real-time information sampling of buildings' thermal energy consumption are greater than 200 KHz. Two columns of VXI additional bus pins are used to integrate the real-time information of buildings' thermal energy consumption. ZigBee is used for monitoring information collection and integrated information processing and the program loading of the buildings' thermal energy consumption intelligent monitoring system is carried out in the main control DSP chip (Yin et al., 2013). The smoke sensor shown in Figure 3 is used for smoke collection. The smoke sensor used in the thermal energy monitoring system of buildings is made of the tin dioxide (SnO2), which has low conductivity in clean air.

Figure 3 Smoke sensor for thermal monitoring of buildings (see online version for colours)



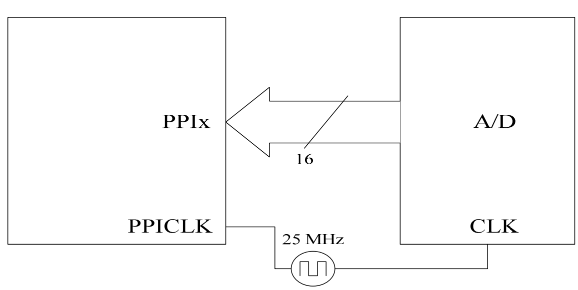
In the peripheral devices of the energy consumption monitoring system, the ZigBee IoT module uses a fixed IP address to implement the networking design of network array. The IO port of CC2530 is connected to the OUT port and the infrared sensor is used as the bottom module of the monitoring system. ADSP-BF537 is selected as the core control device and the ADM706 with internal clock oscillator is used for clock interrupt control (He et al., 2016).

3.2 Information monitoring module for energy consumption

Based on the above description of the overall structure design and development environment of the system, the DSP integrated signal processor is used to collect data and real-time information of buildings' thermal energy consumption and improve the intelligent control ability of buildings' thermal energy consumption monitoring (Zhang et al., 2017). The hardware cost of the intelligent monitoring system is designed within a reasonable range. The core equipment includes dispatching equipment, embedded building energy consumption monitoring platform system, building energy consumption data acquisition device, main control DSP chip, smoke sensor. Core equipment and peripheral equipment operating costs are in accordance with the relevant national regulations to control within a reasonable range. The embedded Linux system is used to construct the core control module of the buildings' thermal energy consumption monitoring system to realise the loading of the control program. During the program loading process, the cross-compilation method is adopted as the BootLoader and the system function structure module designed in the IoT environment includes the information acquisition module of buildings' thermal energy, the integrated control module, the energy consumption detection module, the IoT module and the human-machine interface module (Dou et al., 2016). The hardware design of each functional module is described as follows:

1 Thermal radiation sensing module. Wireless thermal radiation monitoring node: In order to ensure the accuracy of the monitoring result as much as possible, a wireless thermal radiation sensor is used as the data acquisition device in the thermal radiation data acquisition module. When monitoring the thermal radiation data in the building space, the wireless thermal radiation sensor needs to be set inside the wireless thermal radiation monitoring node, using signal processing, single bus communication and AD conversion modes. Thermal radiation data can be collected by thermal radiation sensor firstly, then the thermal radiation signal can be further amplified through signal conditioning for the collected data. After that, the amplified signal is calibrated and corrected by the A/D converter and at last the thermal radiation data is transmitted through single bus communication to ensure the accuracy of thermal radiation monitoring. Thermal radiation is a natural phenomenon in buildings when thermal energy consumption occurs. Some heat radiation is inevitable in buildings, but high concentrations of thermal radiation will affect human health. In order to ensure the stable operation of people's production and life, it is necessary to set up thermal radiation monitoring nodes for thermal radiation in the building space, so as to monitor the thermal radiation concentration in the building in real time to ensure the safety of people's living environment.

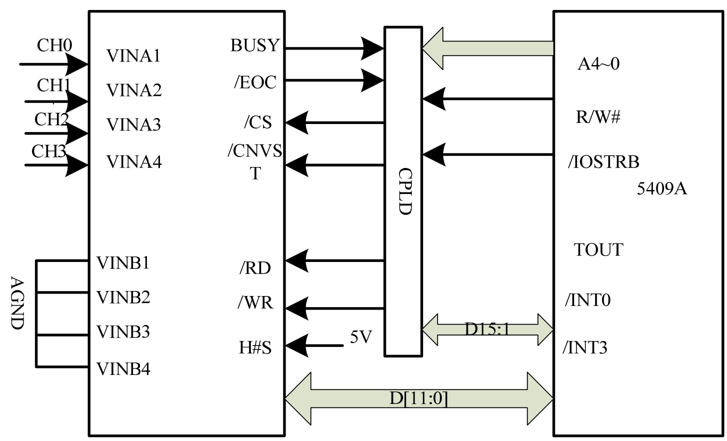
Figure 4 Hardware composition of information acquisition module of thermal energy of buildings



2 Integrated control module. Based on the thermal radiation data sampling of buildings' thermal energy consumption by using AD9225 of AD Company, the LCD controller is designed to carry out intelligent control of information transmission of buildings' thermal energy consumption monitoring. The 8-bit A/D chip is used for

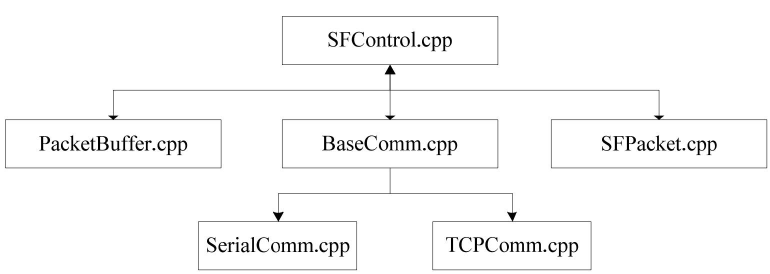
AD conversion control of real-time monitoring information of thermal energy of buildings and the floating-point DSP and fixed-point DSP are adopted for cross-compilation design. Combined with low-voltage reset and power-down monitoring method, the integrated control of thermal energy intelligent monitoring system of buildings is carried out. The PCI9054 bus design method is used for upper computer communication and the clock circuit is used for the internal clock oscillation processing of the buildings' thermal energy consumption intelligent monitoring system (Choi, 2014) to realise the distributed data transmission of the upper computer communication and the buildings' energy consumption monitoring under the IoT technology. The hardware composition of the integrated control module is shown in Figure 5.

Figure 5 Hardware configuration of the integrated control module (see online version for colours)



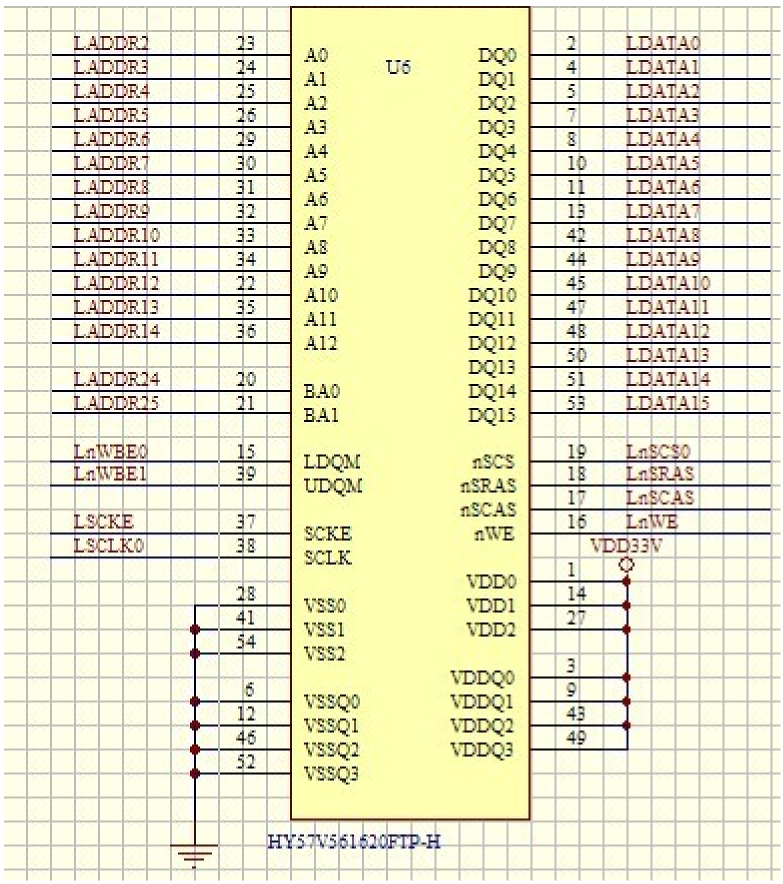
3 IoT module. The star network topology is used to design the sensing information networking. The IoT networking module adopts the heterogeneous and hierarchical wireless sensor network design and uses the media access control (MAC) layer protocol as the transmission control protocol of the IoT. Commands and events are declared in the interface to complete different functions and realise the IoT networking design. The hierarchical structure of the IoT module is shown in Figure 6.

Figure 6 Hierarchical structure of IoT module



4 Human-machine interface module. The human-computer interaction interface module adopts the C mode to compile the driver program for the thermal energy consumption monitoring of buildings and sets the clock signal; LHOLD, as the input signal, uses the embedded ARM addressing technology to carry out the integrated information sampling and bus scheduling of the thermal energy consumption monitoring of buildings and uses the UNIX-like operating system for interface compilation. The design of the human-machine interface module is realised as shown in Figure 7.

Figure 7 Human-machine interface module (see online version for colours)

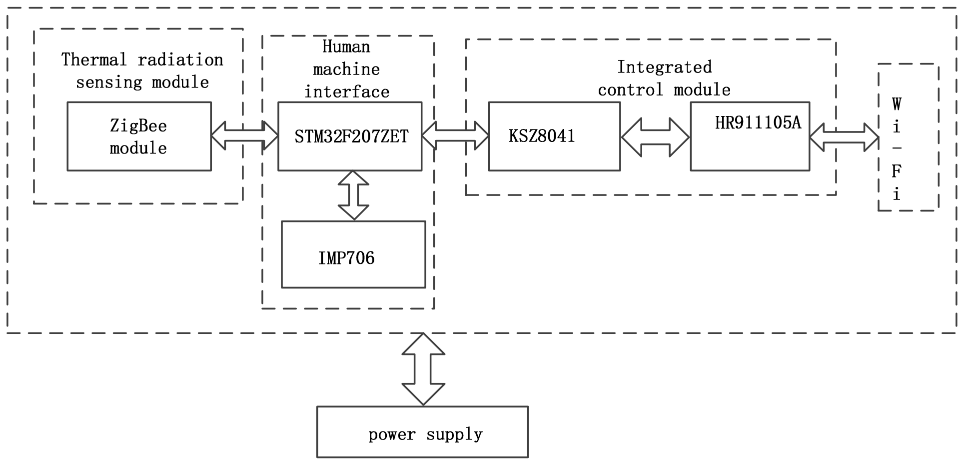


According to the above modular design structure, the hardware development and design of the energy consumption monitoring system is carried out in the ADSP-BF537 processor and the IoT technology is adopted to realise the optimal design of the thermal energy consumption monitoring system of buildings.

5 Wireless intelligent gateway. In the intelligent monitoring system of buildings' thermal energy consumption, the key step is the design of wireless intelligent gateway. Therefore, the switch design of the wireless gateway should ensure the

quality of the switch. The wireless intelligent gateway needs to set the ZigBee module and this module can assist the switch to combine with other wireless monitoring devices in the building space to form a closed-loop wireless intelligent control network. When the intelligent gateway receives the control signal, the intelligent monitoring of thermal energy consumption of buildings can be completed in real time.

Figure 8 Structure diagram of intelligent gateway

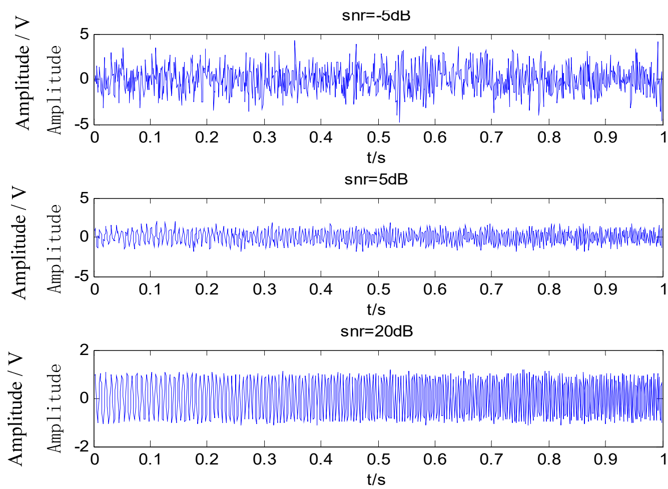


4 System simulation test and result analysis

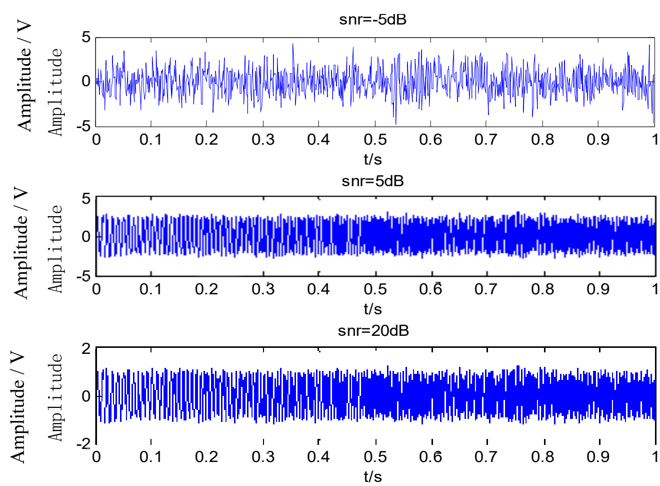
In order to test the application performance of the buildings' thermal energy consumption intelligent monitoring of the method in this paper, the simulation experiment is carried out by comparing the designed system with the methods proposed in the literature He et al. (2011) and the literature Qi et al. (2015). In the noisy environment, the signal-to-noise ratio of the system will affect the accuracy of the system and the matching degree of the output time-domain waveform of the thermal energy consumption monitoring system. Therefore, the time-domain waveform matching degree of the detection system is adopted to evaluate the accuracy of energy consumption detection of the system and the precision of the system is evaluated through multiple iterations.

The experiment uses the GUI panel design tool to design the parameter configuration interface. In the Simulink, the TaskBasic().runTask() scheduler of the TaskBasic.postTask() task is called and the init() command function is used to initialise the task queue and data structure. In one component, the task keyword of nesC is used to declare a task and the function in the interface of the IoT completes the function of the duplex channel through the keyword command and event. The energy monitoring command or configuration parameter is completed in the file MinePressureCollectionC.nc. The collect cycle of buildings' energy consumption is 12 s, the data sampling length of buildings' thermal energy consumption is 2000, the training sample number is 100 and the monitoring time is set to 24 h. According to the above simulation environment and parameter setting, the thermal energy consumption intelligent detection of buildings is performed. Under the condition of the signal-to-noise ratio of –5 dB, 5 dB and 20 dB respectively, the output time-domain waveform of the thermal energy consumption monitoring is obtained as shown in Figure 9.

Figure 9 Output time-domain waveform of the thermal energy consumption monitoring of buildings, (a) intelligent monitoring system for thermal energy consumption of buildings under the IoT technology (b) literature five systems (c) literature six systems (see online version for colours)

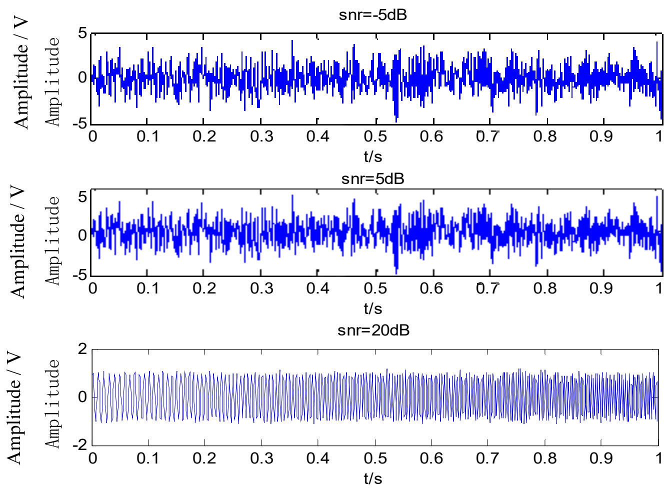


(a)



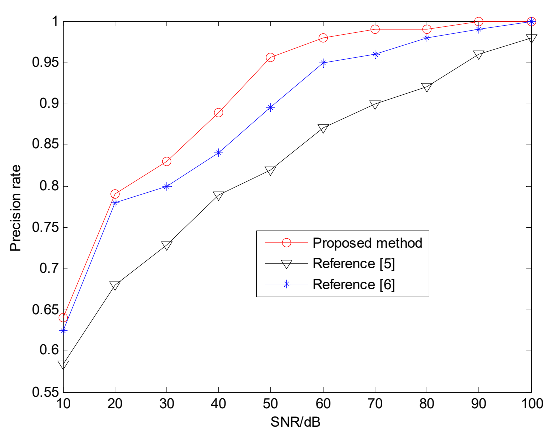
(b)

Figure 9 Output time-domain waveform of the thermal energy consumption monitoring of buildings, (a) intelligent monitoring system for thermal energy consumption of buildings under the IoT technology (b) literature five systems (c) literature six systems (continued) (see online version for colours)



(c)

Figure 10 Comparison of monitoring accuracy (see online version for colours)



According to the monitoring results of Figure 9, the literature He et al. (2011) system obtains that the output time-domain waveforms of the thermal energy consumption monitoring are not matched under the condition of signal-to-noise ratio of 5 dB and 20 dB. The literature Qi et al. (2015) system obtains that the output time-domain waveforms of the thermal energy consumption monitoring are not matched under the condition of signal-to-noise ratio of 5 dB and –5dB. The system designed in this paper obtains that the output time domain waveforms of the thermal energy consumption monitoring are consistent under the condition that the system signal-to-noise ratio is –5dB, 5 dB and 20 dB. The setting accuracy is 100%. According to the matching ratio of the three sets of waveforms, the matching degree of the literature He et al. (2011) and the literature Qi et al. (2015) is 33.33%. The system proposed by this paper can accurately test the buildings' thermal energy consumption and the monitoring accuracy of buildings' energy consumption expenditure is 66.66% higher than that of the other two systems. The accuracy of energy consumption monitoring by different methods is tested and the comparison results are shown in Figure 10.

Analysis of Figure 10 shows that as the number of iterations increases, the accuracy for the thermal energy consumption monitoring of buildings increases gradually. The monitoring accuracy of the method proposed in this paper is 12.7% higher than that of the traditional method and the real-time performance is improved by 21.9%. Therefore, its performance is superior.

5 Conclusions

The optimisation design method of intelligent monitoring system for buildings' thermal energy consumption is studied. The network architecture of intelligent monitoring system for buildings' thermal energy consumption is constructed based on IoT technology. By combining the smart home construction technology, the optimisation design of intelligent monitoring system for buildings' energy consumption is realised. This paper proposes a design scheme for intelligent monitoring system of buildings' thermal energy consumption under the IoT technology and the implementation steps are as follows:

1. Construct the analysis of the overall structure and hardware composition of the intelligent monitoring system for buildings' thermal energy consumption.
2. The DSP integrated signal processor is used for data acquisition and real-time information processing of thermal energy of buildings to complete the acquisition and data conversion of thermal radiation information.
3. Set up energy consumption information monitoring module based on IoT technology and build a wireless sensor network model for energy consumption monitoring based on this to realise intelligent monitoring of buildings' thermal energy consumption.

The method proposed in this paper has higher accuracy and better real-time performance in buildings' thermal energy consumption monitoring. On this basis, the research work in the future is the development of new energy sources for intelligent buildings, aiming at finding the right energy in the new energy sources to make the intelligent monitoring system of building thermal energy consumption more perfect.

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