THERMAL ENERGY DATA MONITORING SYSTEM BASED ON DATA COLLECTION OF THERMAL METERING EQUIPMENT OF INTERNET OF THINGS

by

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To solve the inaccurate measurement of the traditional thermal energy network, the paper designs a thermal energy network monitoring and control system based on GPS and Ti3367 wireless transmission and reception based on the IoT. First, the paper designs the monitoring and control system's overall function and topology, including the management layer's complex functions, the data aggregation layer, and the data acquisition layer. The paper then designs the system's hardware structure based on the IoT, including the connection design of the hardware circuit structure diagram of the data aggregation layer and the data acquisition layer. Finally, the paper realizes the system's software flow design, including system initialization and wireless data receiving and sending flow design.

Key words: *IoT, wireless transmission, data collection, monitoring and control*

Introduction

With the gradual improvement of people's living standards, more and more northern cities or cities in the north are heating and cold-proof in winter. With the commercialization of heat energy, the conflicts between residential residents and heating companies caused by inaccurate billing have become serious. Accurate measurement of thermal energy technology has become a new requirement for enterprises. Traditional thermal energy measurement methods have disadvantages such as troublesome construction, poor penetration, limited transmission distance, and inability to control data in real-time. With the rapid development of wireless technologies such as 4G and 5G, it is realized through wireless transmission technology [1]. Thermal energy metering, monitoring, and control have become a necessary data collection system for heating companies.

According to the demand for thermal energy network measurement, the paper designs a wireless transmission thermal network monitoring and control system based on a Ti3367 embedded chip. The system uses GPRS wireless technology and Ti3367 wireless transmission module to realize the monitoring and control of thermal energy network measurement system [2]. Through real-time transmission and real-time interaction of data such as water temperature, water pressure, and start time of thermal valve control of the thermal energy network, the user's thermal energy consumption is accurately measured, which solves the opacity of thermal energy billing between heating enterprises and users and other issues, real-time monitoring of thermal energy, accurate billing and real-time collection and backup of thermal energy network data.

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The functional design of the monitoring and control system

The main functions of the thermal energy network monitoring and control system are designed:

– Thermal energy network real-time parameter monitoring, monitoring metering, temperature, and pressure value recording and over-line alarms.
– Thermal energy network data measurement management to realize user data usage Records*, etc.*
– Real-time control of the heating network controller, parameter settings of the heating network (heating temperature and heating pressure*, etc.*
– Wireless collection and transmission of heating network metering data, data analysis of the heating network system, data statistics, and data backup*, etc.*
– Daily management of the system, including data printing, data query, and data modification*, etc.* The thermal network monitoring and control system realizes the automatic control of heating enterprises' thermal energy, which can meet the requirements of energy-saving, emission reduction, and thermal accuracy metering, *etc.*

The overall structure design of the monitoring and control system

The monitoring and control system's topological structure is designed as a three-layer structure as a whole: management layer, data aggregation layer, and data acquisition layer.

Management

The management layer's core equipment is the industrial control machine, which realizes the server's dual functions and the client. The server function is mainly to realize the real-time data collection of the wireless transmission system and the real-time storage of the client's thermal energy metering data and meet the real-time monitoring of each node [3]. The client mainly realizes real-time collection and real-time monitoring of parameters such as controller temperature and pressure through GPS and relay collectors.

Relay layer

The relay layer's core device is the data converge, which is also the core of the monitoring and control system, including the GPS communication and Ti3367 wireless data transceiver module. The field collection layer wirelessly transmits the collected real-time data to the management layer through the GPS module. Relay layer The Ti3367 wireless data transceiver module is used between the on-site acquisition layer to realize data upload and return.

Data collection layer

The data collection layer comprises two parts: a data controller and a room temperature collector. The data controller is placed in the hoist way, transmitting the temperature data, pressure data, and the start and stop time of the thermal network control valve to the relay layer. The room temperature sensor mainly realizes real-time room temperature acquisition and room temperature setting control [4]. The overall structure of the monitoring and control system is shown in fig. 1.

Monitoring and control system hardware design

The monitoring and control system's hardware part comprises two parts: the data aggregation layer and the data acquisition layer.

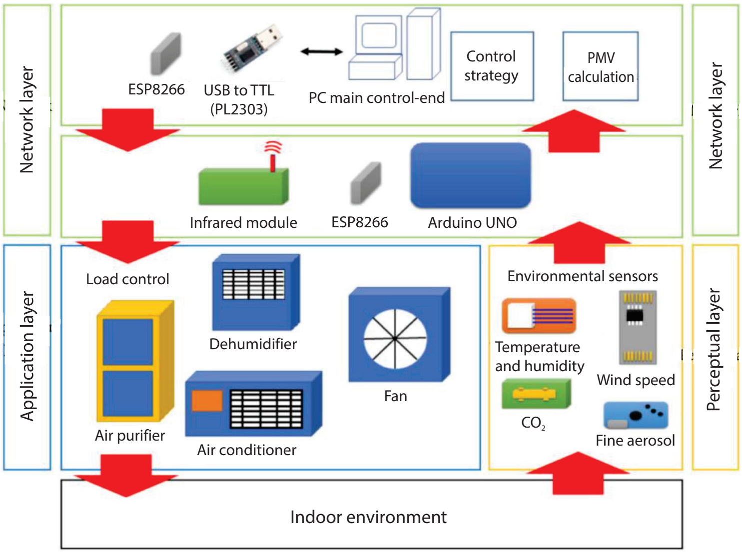

Figure 1. The overall structure of the monitoring and control system

Data convergence layer

This layer is mainly composed of a GPS communication module and Ti3367 wireless data transceiver module. The GPS uses H3C's M6921. It exchanges information with Ti3367 through the UART interface and uploads the server's data signals and control commands and the host computer's thermal network, and post back.

Data collection layer

The Ti3367 chip uses the SPI interface to perform data transmission with the main control microcontroller chip C8051F310 and realizes the data interaction function between the data acquisition and convergence layers. The convergence and data acquisition layers are completed by the Ti3367 wireless transceiver chip [5]. The monitoring and control system the hardware system design is shown in fig. 2.

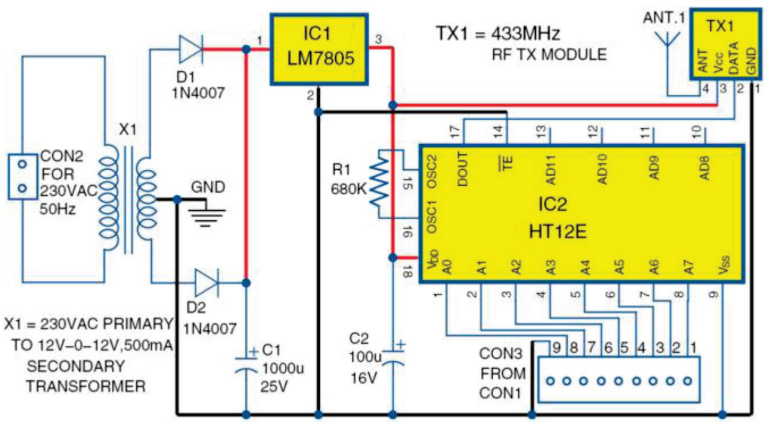

Figure 2. The Ti3367 wireless transceiver module

The Ti3367 provides three standard SPI interfaces (No. 13-16) to meet the system's later expansion needs. The NIRQ interface can interrupt the system's output, and the SDN interface can detect the system's working status. When SDN = 0, Ti3367 is at a Normal working state and when SDN = 1, the system is in a power-down state. When the system is power-off, the memory content is lost, and the SPI interface is in sleep mode [6]. When the system continues to supply power, the SDN level state will automatically switch and follow the control command automatically switch working mode.

Monitoring and control system software design

The monitoring and control system software mainly includes three parts:
– The system initialization, including the initialization of the main control chip, the interface initialization and the initialization of Ti3367*, etc.*
– The wireless transmission program design, after the data is read and written, the data is configured with the check code and the data link, pre-identifier and feature synchronization bit code*, etc.*
– The wireless receiving program mainly performs data CRC verification determine whether the received data is lost, out of order, and errors.

Initialization procedure

The C8051F310 single-chip microcomputer chip first performs the system initialization function. After the system is powered on, the C8051F310 is in the default working mode. The system initialization setting needs to be performed according to the thermal network monitoring and control requirements. The registers' configuration is realized by controlling the UP-port's interaction and the DOWN port, and the resources of the single-chip are divided [7]. To the I/O conversion interface. The system initialization also needs to initialize the signal frequency, working status, and data rate of the Ti3367 wireless module and the GPS communication module.

Wireless sending program

After the control chip C8051F310 circuit board, Ti3367 and various peripheral interface states are initialized, complete the initialization of the control field in the Ti3367 register, set the length of the data packet and use the SPI interface to continuously write the 7fh of the register, and switch the antenna switch to TX State, fill the collected heating network data into the FIFO interface. Then, the data packet's automatic control transmission function is realized through the initialization interrupt instruction and the data packet transmission instruction. When the data transmission is completed, the level value of the pin NIRQ is passed to determine whether to execute the read interrupt status command. When NIRQ is read as low level, read the interrupt status, and complete the wireless data transmission operation. The wireless transmission program flow is shown in fig. 3.

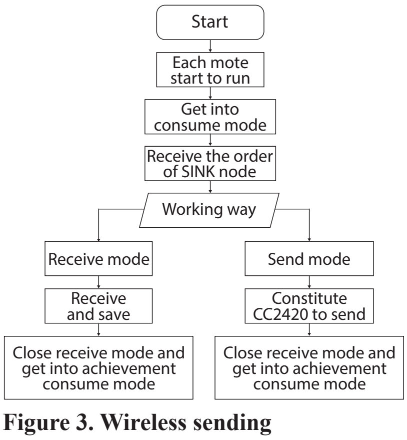

Figure 3. Wireless sending program flow

Wireless receiving program

After the control chip C8051F310 circuit board, Ti3367, and various peripheral interfaces are initialized, the sending program's thermal network data is collected from the RX FIFO memory by reading the register 7th. After the control field's configuration is completed, the level value of NIRQ Judge the wireless receiving program's status. If NIRQ = 0 is the low level state, it indicates that Ti3367 is in the data receiving state. The Ti3367 register 4bh is used to read the length of the data [8]. The level state of the pin NIRQ is useful for judging whether the system has a valid data Package and whether it can perform data reception plays a key role. The wireless receiving program flow is shown in fig. 4.

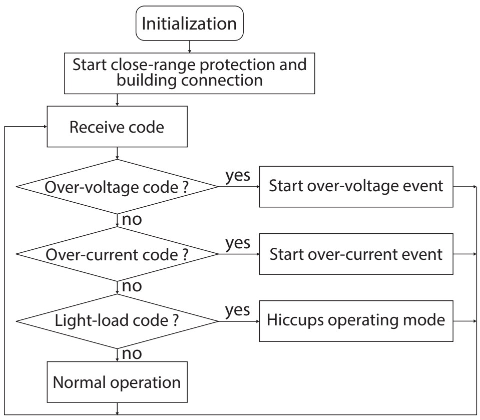

Figure 4. Wireless receiving program flow

Temperature and pressure calculation

From the bridge and operational amplifier circuit in fig. 5, the formula for solving the PT100 resistance can be obtained:

$$\left[\frac{R_{30}}{R_{30}+R_{27}}-\frac{R_{31}}{R_{31}+R_{pt}}\right]V_{pt}Gain=\frac{AD_{\text{value}}3.3}{4096}V_{\text{refo}} \tag{1}$$

where R_{pt} is the resistance of PT100, V_{pt} – the connected to the positive pole of PT100, which is the power supply of the bridge, AD_{value} – the average value of ADC sampling multiple times, *Gain* – the operational amplifier gain, and V_{refo} – the operational amplifier bias voltage:

$$R_{pt}=\frac{2000.0}{\left(\dfrac{2.0}{2.82}\right)-\left[\dfrac{Get_{\text{Volt}_{AD9}}-1.25}{2.5\cdot 28.778}\right]}-2000.0 \tag{2}$$

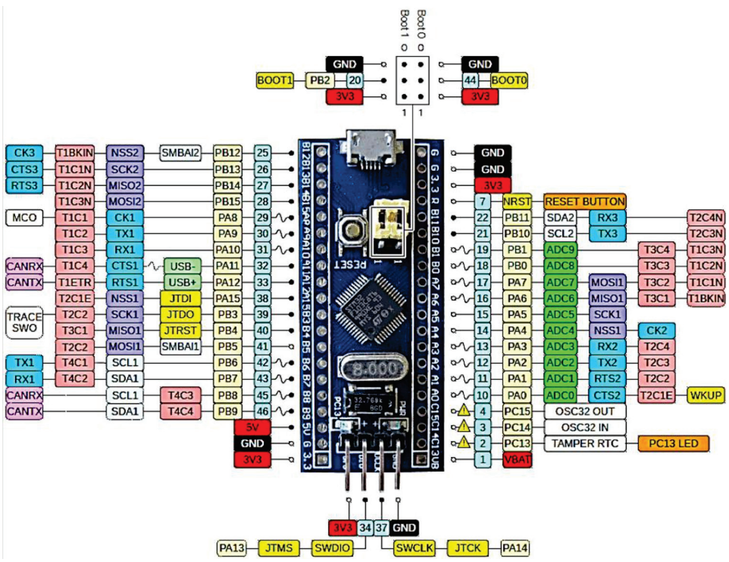

Figure 5. The STM32 minimal system

The Get$_{\text{Volt}}$ is the average of 16 voltages collected by ADC. According to the equation of the Electrotechnical Commission standard IEC751 in the temperature range of –78-0 °C:

$$R_{pt} = R_0(1 + At + Bt^2 + C(t-100)t^3 \tag{3}$$

In the temperature range of 0-600 °C:

$$R_{pt} = R_0\left(1 + At + Bt^2\right) \tag{4}$$

where $R_0 = 1000.000\ \Omega$, $A = 3.9083 \cdot 10^{-3}$ °C^{-1}, $B = -5.775 \cdot 10^{-7}$ °C^{-2}, $C = 4.183 \cdot 10^{-12}$ °C^{-4}.

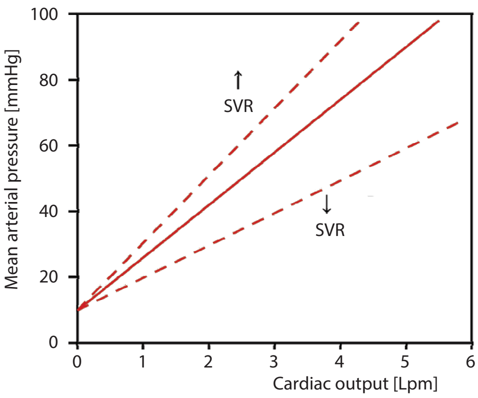

Figure 6. Relationship between pressure and output

With the improvement of the single-chip microcomputer's performance, the piecewise linear function is used to approximate the higher-order equations, and the multiplication and division of floating-point numbers can be directly performed. Here, the Newton iteration method is used, and the operation accuracy of 0.1% can be achieved after three iterations [9]. The pressure transmitter's output current has a linear relationship with the pressure value, as shown in fig. 6. The pressure value of a pressure sensor with a range of 16 MP under 24 V voltage excitation is calculated:

$$P = \frac{AD_{\text{value}}\, 3.3}{4096 \cdot 150} - 4 \tag{5}$$

where P[MP] is the required pressure, AD$_{\text{value}}$ – the average value of ADC sampling multiple times, and ADC reference voltage is 3.3 V, sampling resistance.

Communication protocol

Modbus is one of the network protocols of industrial controllers. The Modbus protocol is a universal language applied to electronic controllers. Through this protocol, controllers can communicate with each other and between controllers and other devices through the network. To conduct centralized monitoring and distributed control. The watchdog function is added to prevent the collector from stopping working and being unable to reset. In the main program, the temperature and pressure are continuously collected and calculated in real-time, and the temperature and pressure values are updated to the Modbus register. If the serial port receives an interrupt, it means that the host sends data via wireless or optical fiber, and the slave performs corresponding processing according to the Modbus protocol.

The data concentrator is the Modbus master of the data acquisition node. The acquisition node only needs to collect data and update it to the Modbus register continuously. To identify different nodes, different Modbus slave addresses need to be set. The master polls the slave after a certain time. The data of the slave is saved in the Modbus register of the master [10]. The data concentrator terminal acts as the Modbus slave of DTU, and all data in it is read and uploaded. Using Mod bus RTU transmission mode, the host sends the slave address and instructions, and the slave responds according to the instructions. The data frame format for the 03 functions (read data function) is shown in tab. 1.

Table 1. Data frame format to achieve 03 functions (read data function)

Host send		Slave response	
Start	3.5 characters	Start	3.5 characters
Device address	0 × 01	Device address	0 × 01
Function code	0 × 03	Function code	0 × 03
Data address H	1 byte	Number of data	1 byte
Data address L	1 byte	Data 1H	1 byte
Number of data	1 byte	Data 1L	1 byte
CRC check H	1 byte	Data 2H	1 byte
CRC check L	1 byte	Data 2L	1 byte
End	3.5 characters	Data NH	1 byte
		Data nL	1 byte
		CRC check H	1 byte
		CRC check L	1 byte
		End	3.5 characters

The agreement stipulates that 3.5 characters of waiting time are required at the beginning of the transmission or the end of a frame of data transmission, and the device address, function code, data register address, number of reading data, and CRC are sent sequentially in bytes. The Modbus slave receives data through the serial port interrupt [11]. When the address matches, it will respond to the host. It also takes 3.5 characters to wait before and after a frame of data. The slave responds by sending the device address, function code, and reading data in bytes. N data values, CRC check.

Monitoring and control system testing

To test the wireless transmission monitoring and control system design's reliability and stability, the paper used nine sets of *transmitting module-receiving module* experiments to compare and verify. The experimental site was set in an open area, and the longest communication distance was set to 2000 m. The operating frequencies of the wireless radio frequency transceiver modules are set to 410.80 MHz, 411.80 MHz, 412.80 MHz, and other nine center frequencies, the bandwidth is 118.6 kHz, the frequency offset is set to ±15 kHz, and 6000 sets of data test packets are sent. The test results are listed in tab. 2.

Table 2. Test results

Grouping	Center frequency [MHz]	Transmission rate [kbps]							
		2.8	9.4	30	60	100	120	180	300
1	410.8	0	0	0	0	0	0.045	0.042	0.026
2	411.8	0	0	0	0	0	0.023	0.025	0.029
3	412.8	0	0	0	0	0	0.047	0.05	0.031
4	413.8	0	0	0	0	0	0.023	0.025	0.008
5	414.8	0	0	0	0	0	0.025	0.048	0.022
6	415.8	0	0	0	0	0	0.019	0.046	0.034
7	416.8	0	0	0	0	0	0.041	0.026	0.016
8	417.8	0	0	0	0	0	0.019	0.028	0.027
9	418.8	0	0	0	0	0	0.028	0.044	0.048

It can be seen from the test data in tab. 2 that when the data transmission speed is lower than 100 kbps, the communication error rate is 0, which is in a good transmission environment. When it exceeds 120 kbps, the communication system has a certain error rate, but the highest value Not more than 0.05%. After testing, it is proved that the wireless transmission system of the thermal energy network has the advantages of long transmission distance, large penetration ability, and low communication error rate.

The DTU regularly reads the data in the data concentrator and uploads it to the cloud. Figure 7 is the operational data of a set of equipment used for secondary development in the USR cloud transparent transmission cloud management system with DTU. Realize the remote monitoring of the equipment from the PC terminal. Figure 8 shows the change of the outlet water temperature curve when the system is working. It can be seen from the graph that the outlet water temperature of the heat pump starts from 28 °C and stabilizes at approximately 60 °C after a period of operation. According to the CO_2 heat pump's working status, the system alarm conditions are: exhaust pressure exceeds 12 MP, the exhaust temperature is greater than 125 °C, outlet water temperature is greater than the set value 12 °C, and low pressure is less than 1.8 MP.

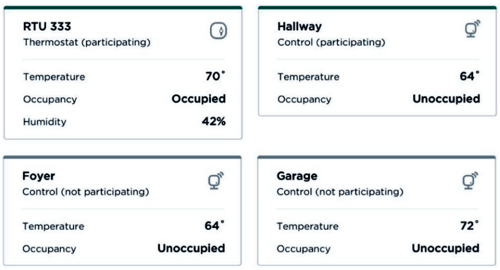

Figure 7. The PC remote data display

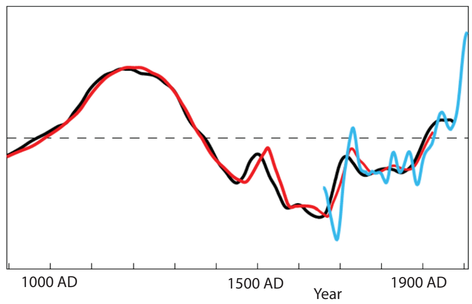

Figure 8. Temperature curve

Conclusion

In this paper, a set of thermal energy network metering monitoring and control system based on wireless radio frequency transceiver technology is designed. The system uses GPS wireless communication technology and Ti3367 wireless data transmitting and receiving module to realize the monitoring and control of the thermal energy network metering system. The usage has been accurately measured, solving the opacity of heat energy billing between heating companies and heat energy users, and realizing real-time monitoring and accurate billing of heat energy and real-time data collection and backup of the heat energy network.

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