Design of electronic shelf label and Zigbee gateway based on electrophoretic display technology

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Abstract. Aiming at the shortcomings of the current paper shelf label, such as low efficiency of manual replacement, untimely information updating, and complicated management, this paper proposes an electronic shelf label system based on electrophoretic display technology, which is combined with Zigbee gateway to achieve more efficient data communication and management. The electronic shelf label system designed in this paper consists of three parts: server, Zigbee gateway and electronic shelf label. Among them, the server uses MQTT protocol to communicate with the Zigbee gateway, and the electronic shelf label uses three-color electrophoretic electronic paper as the display terminal.

Keywords: electronic shelf label, Zigbee gateway, electrophoretic display, MQTT

1 INTROUDUCTION

With the rapid development of the retail industry, there is an increasing demand for improving sales efficiency and customer shopping experience[1]. In this context, Electronic Shelf Label (ESL) as an emerging technology has gradually become an important part of the retail industry. Traditional paper labels are no longer sufficient due to their inconvenient updating process, time-consuming nature, and labor-intensive drawbacks[2][3]. In contrast, ESL offer the advantage of real-time updating, improving operational efficiency and saving labour costs. They are suitable for large shopping malls or warehouses that require a large number of labels[4]. Electronic paper, based on electrophoretic display technology, is a new type of display device that is now widely used in ESL due to its advantages of low power consumption, high visibility, and long life, compared to traditional LCD display[6].

ESL system is an applied electronic system placed on the shelves of merchandise that is capable of receiving real-time information on merchandise such as price through wireless communication and displaying it through an electronic paper display. Although the ESL system has made some progress, there are still some problems and shortcomings in the current market. Firstly, most of the existing ESL systems use

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Bluetooth or Wi-Fi for wireless networking[6], which has limited ability to connect devices and high system power consumption, respectively. Secondly, many ESL systems still need improvement in terms of remote control performance. Zigbee technology is a low-power, self-organising, low-cost, highly networkable, and highly reliable wireless bidirectional communication technology[7][8]. It can effectively improve the updating speed and reliability of the ESL system, as well as reduce the overall energy consumption of the system. Based on the above background and problems, this paper proposes the design of an electronic shelf label and Zigbee gateway based on electrophoretic display technology, which can remotely modify and automatically update the label information, based on the above background and problems.

2 SYSTEM OVERVIEW

2.1 ESL system overview

The ESL system is shown in Figure1.The system mainly consists of three parts: server, Zigbee gateway and electronic shelf tag. The roles of its parts are as follows.

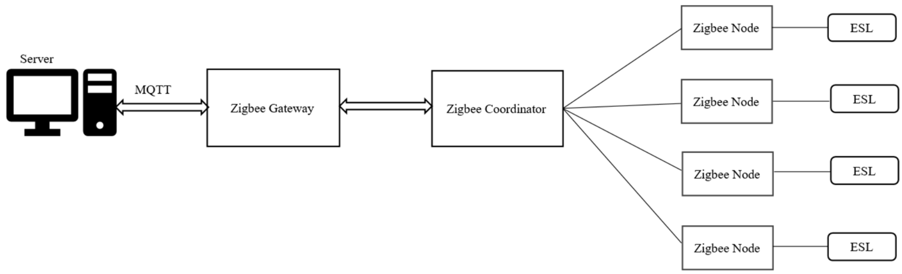

Fig. 1. System structure diagram.

Server: The server side includes front-end and back-end parts. The front-end has a visual interface that enables warehouse administrators to add, delete, modify and query commodity information, such as modifying commodity price information. The front-end sends the information to the back-end through socket communication. The back-end sends the changed information to the Zigbee gateway using MQTT protocol.

Zigbee gateway: The Zigbee gateway connects with the server through MQTT. After receiving the information from the server, Zigbee gateway converts the protocol data into Zigbee data and forwards it to the Zigbee coordinator. The coordinator then sends the commodity information that requires modification to the Zigbee module terminal through the Zigbee network.

Electronic Shelf Label (ESL): The ESL in this design uses three-color electrophoretic electronic paper as the terminal device of the system. The ESL is the core part of the system. By connecting with the Zigbee coordinator, it can obtain the information that needs to be displayed by the label, and refresh the display on the electronic paper.

2.2 Introduction to electronic shelf label design

Electrophoretic display (EPD) is a display technology that uses the principle that charged colloidal particles can move in an electric field to achieve alternate color display through the movement of charged substances between electrodes under the action of an electric field. Electrophoretic display technology is a new type of display technology that offers wide viewing angles, ultra-low power consumption, and a paper-like display[9]. The working principle of electrophoretic electronic paper involves the electrophoresis of black and white particles under the influence of an electric field. This process controls the distribution of the two types of particles in a small space, resulting in the formation of different colours on the screen surface. Electrophoretic electronic paper can be classified into microcapsule type and microcup type, based on the shape of the ink capsule[10]. Each microcapsule or microcup contains white, black, and red particles suspended in a transparent liquid. The particles are negatively and positively charged. When an electric field is applied, the particles move to the top of the microcapsule due to homopolarity repulsion. This movement causes the user to see the white, black, and red colors on the block[11].

In this paper, ESL uses three-color electronic paper with a microcup structure, and its three-color Electronic ink(E-ink) system operates on a similar principle to the two-color system, where different voltages are applied so that particles of different colors move to the top and different colors are seen. The microstructure is shown in Figure 2. The ESL comprises an electronic paper screen module and a minimal system board, CC2530, with a user interface. The interface comprises various elements, including the product name, origin, brand, specifications, item number, retail price, and original price. The ESL design diagram is shown in Figure 3.

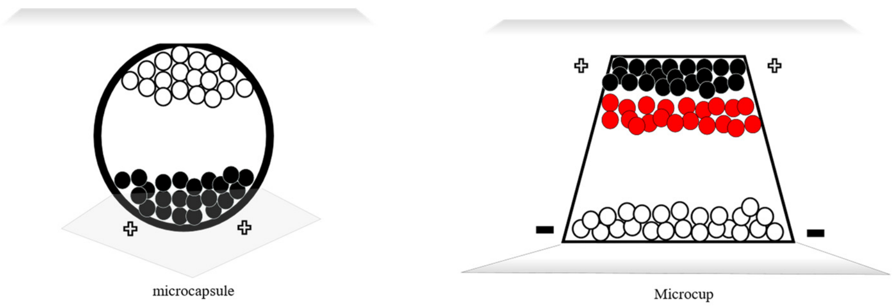

Fig. 2. Schematic diagram of microstructure.

Fig. 3. ESL design drawing.

3 SYSTEM HARDWARE DESIGN

3.1 System hardware overall architecture design

The hardware of the ESL system mainly uses three modules: Zigbee gateway, electronic paper ink screen, and Zigbee peripherals. The Zigbee coordinator connects to the gateway through the serial port connection. The electronic paper ink screen module is mainly controlled by the hardware SPI module of the CC2530 microcontroller. The control-related IOs are controlled by the software. The hardware transceiver on the CC2530 chip facilitates communication between the Zigbee coordinator and the Zigbee terminal node. The Zigbee gateway communicates with the server using the MQTT protocol.

3.2 Zigbee gateway hardware design

The Zigbee gateway in the ESL system design is primarily responsible for converting server data into the data required by the Zigbee module. The hardware platform for the Zigbee gateway consists of six parts: the embedded microprocessor module, the Zigbee module, the serial module, the USB interface module, and the Ethernet interface module. The Zigbee data is accessed through the RS232 serial module and sent to the IoT gateway, while MQTT packets are sent to the server through Ethernet. Figure 4 shows the structure of the Zigbee gateway.

The Zigbee gateway needs to convert commodity data formats between different protocols. The embedded system has the advantage of strong performance for a single application, low hardware device costs, easy installation, and simple upgrade and maintenance. Therefore, the embedded system is used as the gateway platform. The Zigbee gateway in this design is implemented using the Raspberry Pi 3B development board. The Raspberry Pi is a cost-effective and versatile component in wireless sensor network projects due to its numerous interfaces and small form factor. In this particular design, the Raspberry Pi is connected to a router via Ethernet to transmit data to a cloud server. Additionally, the Raspberry Pi is connected to the coordinator via USB, and its low power consumption allows for a power supply voltage of only 5V.

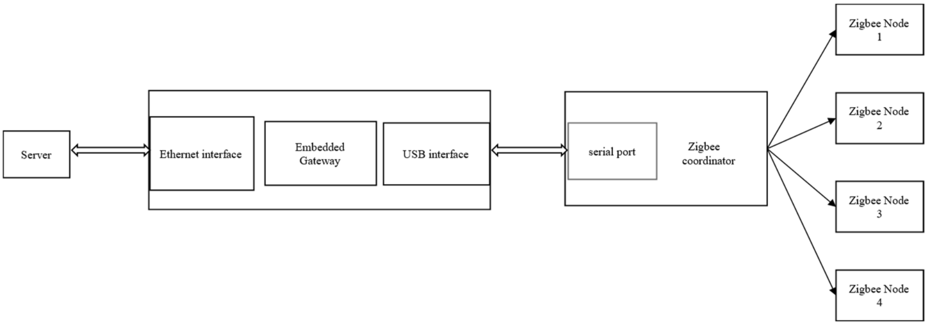

Fig. 4. Zigbee gateway structure diagram.

3.3 Electronic paper display hardware design

When designing ESL system, the display module primarily takes into account cost, power consumption, and durability. The system uses a 2.7-inch electronic paper display based on SPI communication, with a resolution of 264 × 176. It is capable of displaying black, white, and red colours and comes with a built-in driver IC: SSD1680Z8. The electronic paper display module utilises a 24-pin FPC interface to connect with the backplane. The serial input (SDIN), clock (SCLK), chip select (CS), data/command (D/C), busy state (BUSY), and reset (RES) pins are respectively connected to the host output of the CC2530 slave input (MOSI), clock (SCK), P0_6, P0_0, and P0_1 pins. The host output slave input (MOSI), clock (SCK), P0_6, P0_0, and P0_1 pins of the CC2530 are connected to the aforementioned pins. The interface circuit schematic shown in Figure 5 displays the CC2530 and electronic paper display module, connected to P0_6, P0_0 and P0_1 pins respectively.

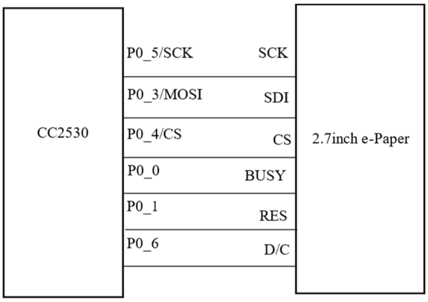

Fig. 5. CC2530 interface circuit with electronic paper.

4 SYSTEM SOFTWARE DESIGN

4.1 Zigbee gateway module software design

The IoT gateway serves as the entry point for devices to access the IoT platform. Its main function is to preprocess data, ensure unified resource description, and execute operational commands. According to the different functions implemented, this paper will Zigbee gateway system for layered design, namely, device access module and gateway internal module, the two modules use Transmission Control Protocol (TCP) for communication, and each module in the sub-division, as shown in Figure 6.

The device access module primarily facilitates the conversion between the MQTT and Zigbee protocols. It also forwards data issued by the cloud platform through the gateway to the Zigbee coordinator, which in turn forwards it to the corresponding Zigbee device terminals. The terminal equipment then completes the corresponding functions. The device access module is divided into two main layers: the sensing interface layer and the protocol adaptation layer. The sensing interface layer is situated at the bottom of the gateway and connects with devices through corresponding interfaces. Its primary function is to enable access to and control of the devices. The protocol adaptation layer completes the conversion of received data into the data model format defined in the IoT platform, enabling access to various types of devices. The gateway's internal modules consist of the data model synchronization layer and the platform communication layer. The synchronisation layer of the data model updates downstream data to the gateway and forwards platform operation information to corresponding devices as instructed. Additionally, it updates the gateway/platform model and uploads the synchronisation packet to the platform. The platform communication layer facilitates bidirectional communication with the IoT server through the MQTT client. This completes authentication access of the gateway devices and reads the registered gateway device model from the IoT resource platform to establish the gateway device model.

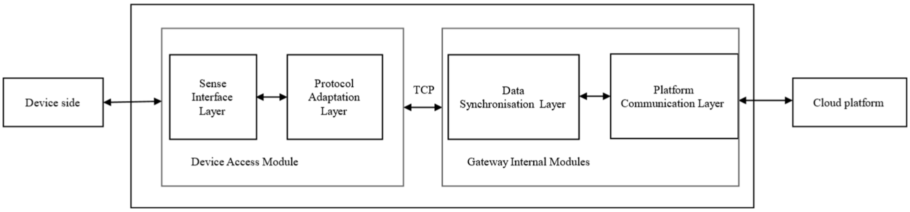

Fig. 6. Gateway layered design architecture diagram.

4.2 Software design of electronic paper driving module

The terminal node displays product information using electronic paper, which is controlled by the CC2530 chip through written commands. The communication between the CC2530 chip and the electronic paper is carried out using the SPI method.

The following Figure 7 shows the overall flowchart of the EPD driver module. To begin the refresh, the EPD must be initialised. This involves controlling the MCU and initialising its peripherals, including the SPI and GPIO peripherals. Next, the EPD must be initialised, including operational functions such as reset and hardware start. Once initialisation is complete, the MCU conFigures the EPD's I/O ports and SPI communication method. The RES pin and BUSY pin serve as control pins for the EPD. When the RES pin is low, the EPD performs a reset operation. The BUSY pin serves as the status output pin of the EPD. When this pin is high, the EPD does not accept external interrupt operations and no commands should be sent to the module. Therefore, when the EPD is in operation, the driver module should set the BUSY pin to a low level. After the EPD power supply is started, the EPD carries out the panel setting, distinguishes the setting, and con Figures the VCOM register. The EPD will load the data and refresh the display upon receiving the refresh command. Figure 8 shows the effect of electronic paper refreshing.

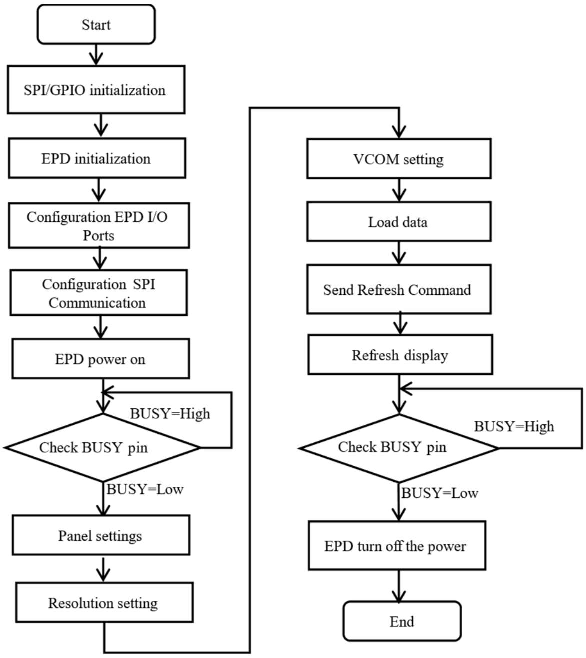

Fig. 7. Overall flowchart of electronic paper driver module.

Fig. 8. Electronic paper physical picture.

5 CONCLUSION

This paper presents the design of an ESL system that meets the requirements of the IoT platform and terminal equipment. The system includes an embedded Zigbee gateway designed using a layered approach. The server converts commodity information data into Zigbee data through the gateway, enabling successful display of commodity information on the terminal equipment. The introduction of electrophoretic display technology ensures that the display remains visible even when the power is cut off, resulting in low standby power consumption. The use of three-colour electronic paper makes commodity information more visible, and the label more eye-catching. The design has been tested and has achieved the expected effect.

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