Design and Implementation of Monitoring and Management System for Tank Truck Transportation

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Abstract: - In order to reduce the wastage and loss of petroleum products in transit, a monitoring and management system is proposed for tank truck transportation. In this system, a vehicle transport recorder is developed to record the operations of inputs and outputs of a tank truck via a kind of Hall Effect switch sensors. Wireless data transceivers are designed to start and stop monitoring in the starting stations and destinations automatically. The information recorded by the vehicle transport recorder is collected by a smart card and then it is transferred to the host management software which is developed to manage the transportation data, alarm messages, devices, archives, etc. The integrated and intelligent system has been implemented and applied to practice, and it reduces the loss of petroleum products during the transportation efficiently.

Key-Words: - Monitoring, management, tank truck, transportation, smart card, CC1100 chip, wireless data communication.

1 Introduction

Nowadays, the wastage of petroleum products in transit becomes higher and higher because of some uncontrollable factors and controllable factors, such as problems of facilities and devices, illegal operations by some people and so on. Along with the increase of petroleum price, the wastage has not only resulted in huge financial loss of petroleum companies, but also brought about the quantity problem of petroleum products. Moreover, it is difficult to monitor and manage the process of tank truck transportation on the spot. Traditionally people use a kind of locking devices, such as lead seals, to lock the input and output (I/O) of a tank truck to prevent illegal operations. However, traditional lead seals can be copied or deciphered easily, and they cannot help people to manage the tank truck transportation conveniently either.

In our previous work, we have proposed a management system for tank truck transportation using smart cards [1], and a wireless data acquisition system based on CC1100 chip [2]. In this paper, a novel monitoring and management system for tank truck transportation is presented. It is not a simple electronic lead seal or other locking device, but an intelligent system based on smart card and wireless data communication technologies. In this system, a kind of vehicle transport recorder is developed to monitor I/O of a tank truck via a kind of switch sensors. A wireless data transceiver is developed to seal I/O at the starting station and unseal I/O at the destination automatically. Once an I/O has been sealed, then any opening or closing operation of it is illegal. The vehicle transport recorder records the information about the illegal operations of I/O. The smart card is used to collect the transportation data from the vehicle transport recorder and transfer the data to the host management software which is developed to manage the transportation data, alarm messages, devices, archives, etc. This integrated system links petroleum storage depots, gas stations, petroleum companies and transportation companies together to form a well organized monitoring network.

The rest of this paper is organized as follows. In Section 2, some related works are given. In Section 3, the system architecture including the design of vehicle transport recorder is presented. Section 4 shows the approach of wireless data communication which is used in both vehicle transport recorders and wireless data transceivers. In Section 5, the algorithm of transportation data analysis is discussed. Section 6 shows the implementation and results of this system followed by the conclusions.

2 related work

J. H. Wu [11] presents a data acquisition system for greenhouses based on the MCU AT89S53 and CC2420 wireless communication module. The data collected by salve is transmitted to the master module which communicates with PC using RS232.

M. Barth [12, 13] introduces a shared vehicle system based on a variety of intelligent transportation system (ITS) technologies (e.g., vehicle location and identification, dispatching, smart cards). Unique hybrid data communication architecture for a multiple-station shared vehicle system is described and designed. This hybrid architecture is composed of vehicle-to-system communications using both DSRC (Dedicated Short Range Communications) and CDPD (Cellular Digital Packet Data) methods.

H. Lee [15] presents a real-time vehicle management system using a vehicle tracking and a car plate number identification technique. The system tracks the vehicles by applying the CONDENSATION algorithm over the vehicle's movement image captured from the cameras.

Y. Wang [16] presents a vehicle monitoring central platform which is establishing a uniform information portal on vehicle monitoring in China. Rather than elaborating sophisticated vehicle monitoring and management approaches, the WebGIS-based system model is striving to develop a technical umbrella for the distributed and Web-based vehicle management systems.

K.H. Xu [17] presents an intelligent vehicle monitoring and management system (IVMMS) based on the multi-net. The system is composed mainly by two major parts: the Mobile Terminal and the Monitoring Centre. It can be used in the vehicles scheduling.

3 System Architecture

The system architecture is shown in Fig. 1. It is a low-cost integrated monitoring and management system composed of a vehicle transport recorder (VTR), a wireless data transceiver (WDT), host management software (HMS), switch sensors, smart cards, database server, IC card reader/writer, etc.

The workflow of the system is shown in Fig. 2. Generally, tank trucks start out from transportation companies. After loading petroleum in the petroleum storage depots, tank trucks transport the petroleum to gas stations, unload the petroleum, and then return to the companies.

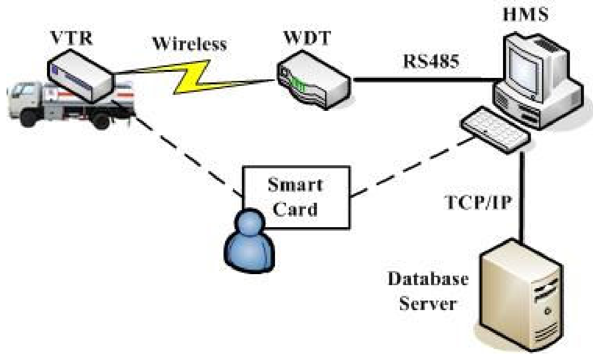

Fig.1. System architecture

When a tank truck is at a starting station, such as a transportation company, a petroleum storage depot or a gas station, the WDT sends a command to the VTR to start monitoring I/O, then I/O is sealed, and it is not allowed to open and close it. Meanwhile, the information of starting station stored in the WDT is also sent to the VTR, so that it is able to know exactly where the transit begins.

When the tank truck arrives at a destination, WDT sends a command to VTR to stop monitoring I/O, then I/O is unsealed, and it is allowed to open and close it to load or unload the petroleum. Of course, in order to know where the transit ends, the information of the destination is also sent to the VTR.

When the tank truck returns to the company, the transportation data recorded is collected by smart cards and is transferred to the HMS for analysis.

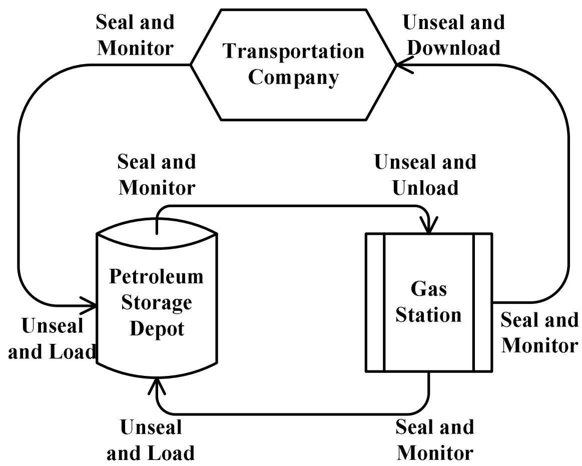

Fig.2. Workflow of the system

3.1 Switch Sensor

There is a Hall Effect [3] switch sensor installed at the shell of tank and the cover of each I/O of a tank truck, which is shown in Fig. 3. The switch sensor connects to a VTR, and it transfers level signals to the VTR serially when I/O is opened or closed.

(1) Input (2) Output

Fig.3. Installation of a switch sensor on an input or an output of a tank truck.

3.2 Smart Card

In this system, a smart card is used to collect data recorded in VTR. Considering the cost and performance, the contact-type smart card with Atmel 24C64 [4] chip is chosen. It provides 65,536 bits of serial electrically erasable and programmable read only memory organized as 8192 words of 8 bits each.

3.3 Wireless Data Transceiver

A wireless data transceiver (WDT) is installed in starting stations and destinations, and it is used to seal and unseal I/O of a tank truck. It communicates with VTR via wireless communication technology (which is introduced in the next section), and it communicates with the HMS via RS485 [5].

3.4 Vehicle Transport Recorder

3.4.1 Architecture Design

A vehicle transport recorder (VTR) is installed in each tank truck, and it is an embedded system including MCU, memory unit, sensor interface, smart card interface, RS232 [6] interface, wireless communication interface and timing unit, etc. The architecture of the VTR is shown in Fig. 4.

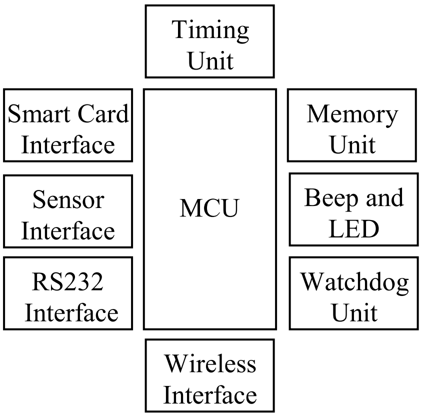

Fig. 4 Architecture of VTR

During monitoring, VTR reads the statuses of switch sensors via sensor interface periodically and rapidly. If any I/O is opened or closed, a data packet composed of the I/O operation information with a timestamp is recorded into the memory; meanwhile an alarm is given via a beep and a LED.

3.4.2 Hardware Design of VTR

In VTR, PIC16F636 [7] chip, which is a 14-pin flash-based, 8-bit CMOS microcontroller with nanoWatt Technology [8], is selected for the MCU, and AT24C64 chip is selected for the additional memory. The other components of VTR are described as follows:

- The sensor interface connects with switch sensors and GPIOs of MCU, so that the MCU knows exactly whether a switch sensor is opened or closed by detecting the level signal of the corresponding GPIO. In order to avoid the signal joggling from environment, it is better for the MCU to detect the GPIO twice to determine whether the level of the GPIO has been changed.
- The smart card interface is used to read or write a smart card. Because the contact-type smart card is instability during its inserting or pulling, it is necessary to protect the smart card well. In VTR, the MCU controls the power supply of the smart card interface via a triode 9012 and a GPIO port. When a smart card is inserted, the MCU gives the GPIO port a high-voltage which makes the triode fire and work, and then the smart card gets the 5.0V power supply and starts to transfer data.
- The RS232 interface is used for configuration of VTR as well as updating the program in the MCU with in-system serial programming interface.
- The wireless interface based on CC1100 [9] chip is used to communicate with WDT. (It is discussed in the next section.)
- The time unit based on DS1302 [10] chip is used to provide a precise time for the system. It communicates with the MCU via a simple serial interface.

The working environment of VTR requires steady power supply, so a lithium battery is selected for the time unit. The other components of VTR use the power supply which is regulated from the power supply of a tank truck.

3.5 Host Management Software

The main functionalities of HMS are described as follows:

- Data Analysis: Analyze the transportation data collected by smart cards, and save the data generated into the database. The algorithm of data analysis is discussed in Section 4.

- Archives Management: Maintain and manage the archives of starting stations, destinations, tank trucks, drivers and smart cards, etc.
- Alarm Management: List and deal with the alarm message generated from the transportation record which includes illegal operations of I/O of tank trucks.
- Device management: Report and deal with the broken devices in the system, such as VTR, WDT, smart cards, etc.
- IC Card Setting: Initialize or cancel a smart card via an IC card reader/writer.
- Remote Control: Administrators can configure a WDT by sending commands to the corresponding WDT, so it is able to start or stop monitoring of a VTR remotely too.

The architecture of HMS is shown in Fig. 5. It can broadly be divided into three layers: the top layer is a presentation layer including report analysis, data display and other GUI; the middle layer is a logic layer including the main functionalities of HMS; the bottom layer is an interface layer for accessing a serial port, an IC Card Reader/Writer and a database.

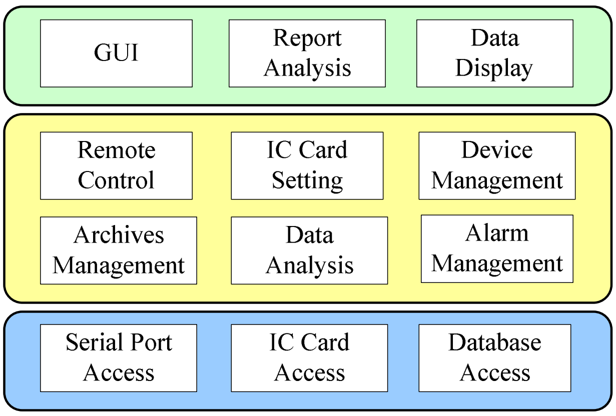

Fig.5. Architecture of HMS

4 Wireless Data Communication

In this section, we proposed a wireless data communication technology based on CC1100 chip. The CC1100 chip is based on Chipcon's 4th generation technology platform based on 0.18 µm CMOS technology. It is a low cost true single chip UHF transceiver designed for very low power wireless applications. Its circuit is mainly intended for the ISM (Industrial, Scientific and Medical) and SRD (Short Range Device) frequency bands at 315, 433, 868 and 915 MHz. Its transmit distance is less than 50m in-building range. It is integrated with a highly configurable baseband modem which supports various modulation formats and has a configurable data rate up to 500 kbps. The communication range can be increased by enabling a Forward Error Correction option, which is integrated in the modem.

4.1 The Working Modes and States of CC1100

For well controlling the data transmission, it is necessary to understand the working modes and states of CC1100. The most commonly used states of CC1100 are IDLE (default), SLEEP, SETTLING (calibration settling), TX (transmit mode) and RX (receive mode). The relations and conditions of these states switching are shown in Fig. 7.

The working modes of CC1100 can be configured to achieve an optimum performance for different applications. This configuration can be done by programming some 8-bit internal registers via the SPI interface. The main parameters which need to be configured include RF output power, Receive/transmit mode, RF channel selection, Data rate, Modulation format, RX channel filter bandwidth, Data buffering with separate 64-byte receive and transmit FIFO, Packet radio hardware support, Forward Error Correction with interleaving, Data Whitening, etc. We can use the SmartRF Studio software to calculate and program the value of each register according to the configuration we need.

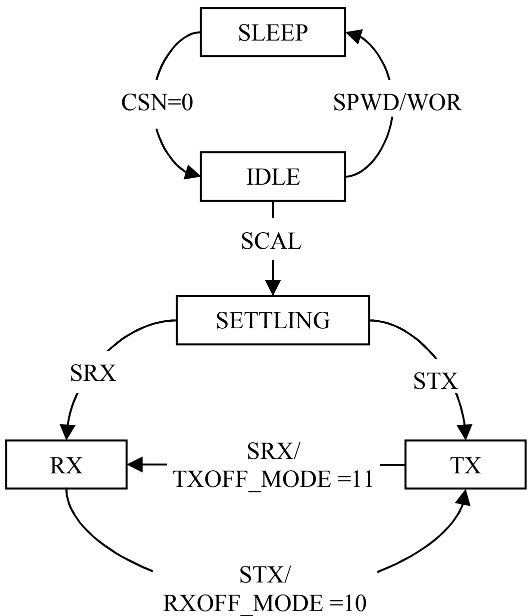

Fig.7. States diagram of CC1100

4.2 Hardware Interface

The interface circuit of PIC16F636 chip and CC1100 chip is shown in Fig. 8. CC1100 chip connects to the MCU with a simple 4-wire SPI compatible interface (SCLK, SI, SO and CSn) and two configurable pins (GDO0 and GDO2), and works as a slave module of the MCU. With this interface, the MCU can do the following operations to the CC1100 chip: configure the working modes; setup the power table; read data from the RX FIFO; writing data into the TX FIFO; switch and check the state; etc. In this system, the wireless data communication is used between VTR and WDT, so both of them contain the interface circuit designed.

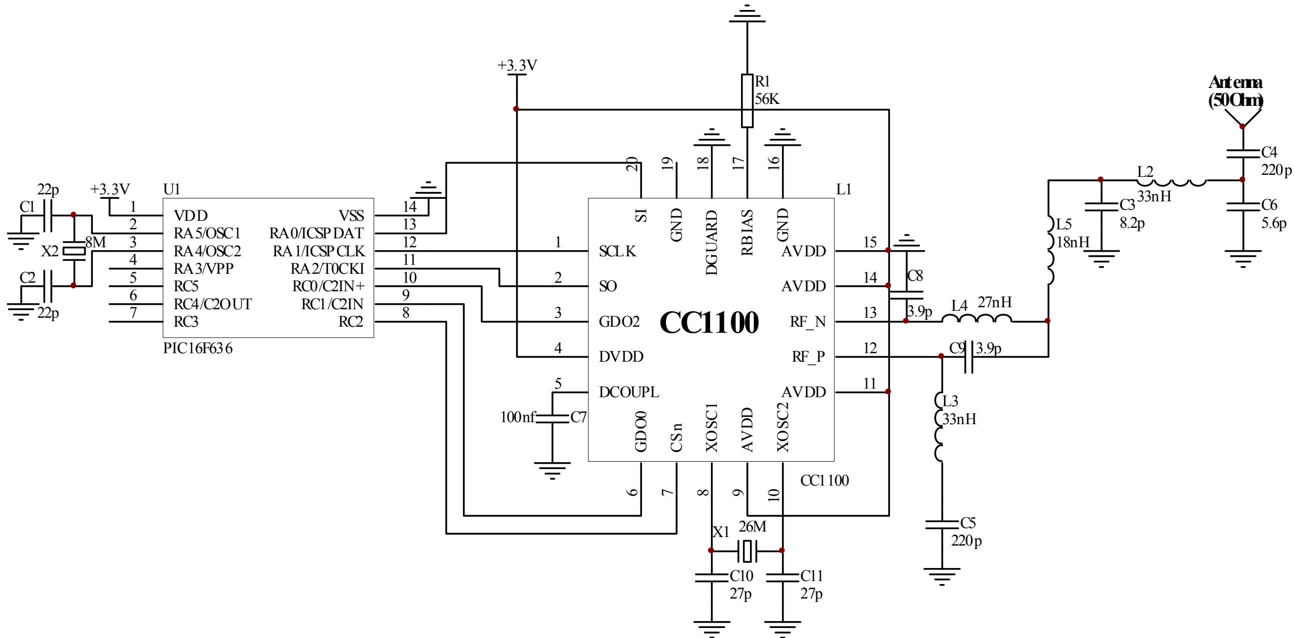

Fig.8. Interface circuit of CC1100

4.2 Software Design

The process of wireless data communication is shown in Fig. 9. First, a WDT sends a search command regularly. When a tank truck passes the acquisition district of the WDT, the VTR installed in the tank truck receives the search command. If the VTR has to transfer the data, it sends its identity to WDT. After the WDT receives the identity of the VTR, It sends a data acquisition command as a response. Then, the VTR starts to transfer the data to the WDT. When all the data has been transferred, the VTR sends a quit request to the WDT. Finally, the WDT accepts the request, and finishes the communication.

Therefore, there are two kinds of packets in the wireless communication: data packets and command packets. The packet format is shown in Table 1. The head of a data packet is defined as “0D 0D 14 CD”, and the head of a command packet is defined as “AA AA 14 CD”. During the communication, the cumulative check method is used to verify the packets.

The control flow of sending and receiving data in the wireless communication is shown in Fig.10, and the functions of sending and receiving data packages are shown in Fig.11.

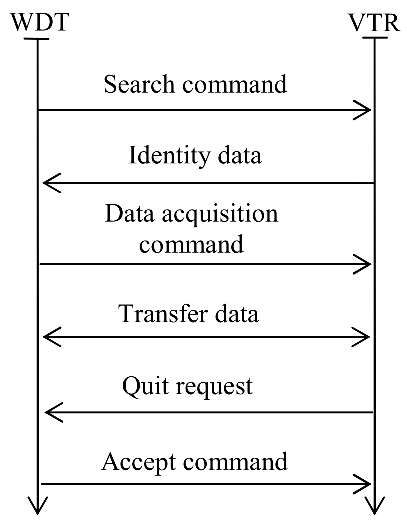

Fig.9. Data Communication Process

Table 1 Packet format in Wireless Data Communication

Items	Bytes
Packet Head	4
Packet Length	1
Command	1
Data Content	> 1
Check	1

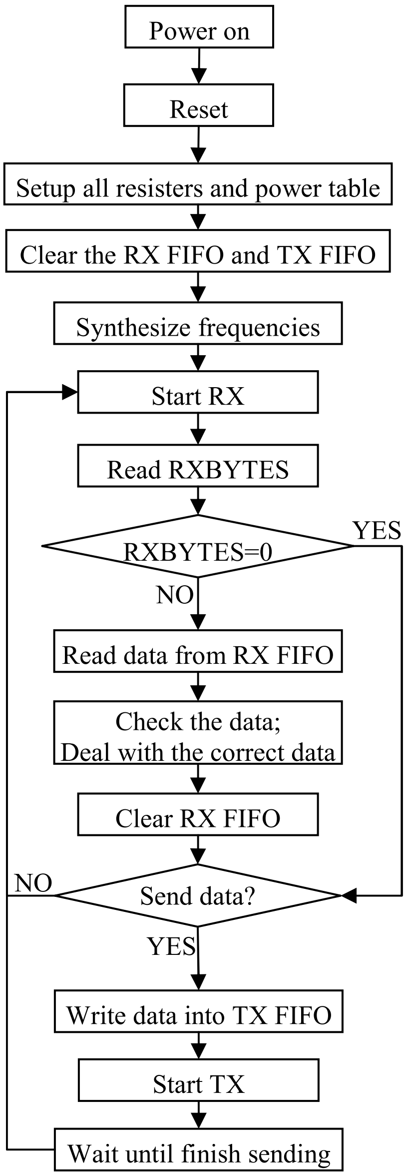

Fig.10. Control flow of sending and receiving data in the wireless communication

```
bit send_package(INT8U *value_array, INT8U len){
    INT8U i,cc_status;
    CC1100_CSN = 0;
    if(ERROR == CC1100_SO_low_check()) return ERROR;
    CC1100_SPI_sendbyte(CC1100_TXFIFO+0x40);
    CC1100_SPI_sendbyte(len);
    for(i=0;i<len;i++){
        CC1100_SPI_sendbyte(*value_array);
        value_array++;
    }
    CC1100_CSN = 1;
    if(ERROR==CC1100_write_command(CC1100_STX))
            return ERROR;
    PIC18_delayus(10);
    while(CC1100_GDO0);
    return OK;
}
```

(1) Send a package

```
bit receive_package(INT8U *value_array, INT8U *len){
    INT8U i, rx_len, rssi_value, crc_value, cc_status;
    INT8U over_time;
    over_time = 0x00;
    if(CC1100_GDO0){
        while(CC1100_GDO0){
            PIC18_delayms(10);
             over_time++;
            if(over_time > 20) {
                 *len = 0x00;
                 return ERROR;
            }
        }
    }
    if(ERROR==CC1100_read_register(CC1100_RXBYTES,&
rx_len,STS)) return ERROR;
    if(rx_len != 0x00){
        CC1100_CSN = 0;
        if(ERROR == CC1100_SO_low_check())
                 return ERROR;
        CC1100_SPI_sendbyte(CC1100_RXFIFO+0xc0);
        rx_len = CC1100_SPI_receivebyte();
        for(i=0;i<rx_len;i++){
             *value_array=
             CC1100_SPI_receivebyte();value_array++;
        }
        rssi_value = CC1100_SPI_receivebyte();
        crc_value = CC1100_SPI_receivebyte();
        CC1100_CSN = 1;
        if((crc_value&0x80)==0x80){
              *len = rx_len;
        }else{
              *len = 0x00;
        }
        if(ERROR==CC1100_write_command(CC1100_SFRX)
)
           return ERROR;
        if(ERROR==CC1100_write_command(CC1100_SRX))
           return ERROR;
           return OK;
    }
}
```

(1) Receive a package

Fig.11. Functions of sending and receiving data packages.

4.3 Discussion

4.3.1 Fault Tolerance

In the system, all the wireless communication components work in the same frequency band, so it is a one-to-many communication between VTR and WDT when there are multiple tank trucks in the wireless acquisition district. To avoid the same frequency interference and the data sources confusion, a kind of time-sharing technology is used to transform the one-to-many communication into one-to-one communication. When WDT regularly sends search commands, VTR receives the command and then sends an identity packet to the WDT. When a WDT receives the response data of a VTR, it sends a data acquisition command to the

VTR. Then, only the VTR with the correct identity is allowed to transfer the data. After the VTR finishes the data transmission, it is not allowed to send the identity command again, and the WDT goes to the beginning and repeats this process until each VTR in the acquisition district finishes their data transmissions.

4.3.2 Other Problems

In this system, the MCU receives data via reading the RXBYTES register of CC1100, but this operation may make the CC1100 fail to receive a complete packet. To deal with this problem, the DGO0 pin of CC1100 is configured with the feature of "keeping high level during sending and receiving data, while keeping low level after finishing transmission", and the MCU is designed to read the state of GDO0 before reading the RXBYTES register of CC1100. If the MCU detects that the GDO0 is in high level, i.e., the CC1100 is sending or receiving data, it will read RXBYTES register after some time's delay.

However, we found that when the GDO0 pin of CC1100 is setup correctly as mentioned above, it may work with incorrect states after working well for some time. So the time duration of the GDO0 in high level is detected; if this duration overruns the allotted time, then the GDO0 doesn't work well and the CC1100 should be reset and re-initialized.

5 Algorithm of Data Analysis

The significant part of the system is to analyze the information recorded in the VTR, i.e., the data collected in the smart card. In this section, we present an algorithm to analyze the data.

5.1 Data format

The data format in the smart card is shown in Table 2. The first byte is used to identify the smart card. The next two bytes are the least significant byte (LSB) and the most significant byte (MSB) of VTR ID, so that the VTR ID is equals to MSB × 256 + LSB. Then, there are 3 bytes BCD codes about the date which includes the information of year, month and day, and 2 bytes BCD codes about the time which includes the information of hour and minutes. The following 4 bytes are the LSB and MSB of the start index and end index of the transportation data respectively. So the bytes of the transportation data can be calculated as: End Index − Start Index. At last, there is the transportation data including the data packets about starting stations and destinations and operations of I/O.

Table 2 Data Format of a Smart Card

Items	Bytes	Value
Card ID	1	C1
VTR ID	2	LSB + MSB
Date	3	BCD Code (YY-MM-DD)
Time	2	BCD Code (HH:MM)
Start Index	2	LSB + MSB
End Index	2	LSB + MSB
Transportation Data	>1	---

The format of a data packet about starting station or a destination is shown in Table 3. The first byte is the data type: the value of A1 means that it is a set of data packet about a starting station; the value of A2 means that it is a set of data packet bout a destination. The next two bytes are LSB and MSB of the number of a starting station or a destination. The following 5 bytes are the BCD codes about date and time.

Table 3 Data Format of a Starting Station or a Destination

Items	Bytes	Value
Data Type	1	A1-Starting Station, A2-Destination
Number	2	LSB + MSB
Date	3	BCD Code (YY-MM-DD)
Time	2	BCD Code (HH:MM)

The data format of an operation of I/O is shown in Table 4. The first byte's value is A3 which describes the data type. The second byte describes the operation: the value of 01 means it is an opening operation and the value of 02 means it is a closing operation. The third byte is the ID of I/O. The following 5 bytes are the BCD codes about date and time.

Table 4 Data Format of an Operation of I/O

Items	Bytes	Value
Data Type	1	A3
Operation	1	01-Open, 02-Close
ID of I/O	1	HEX
Date	3	BCD Code (YY-MM-DD)
Time	2	BCD Code (HH:MM)

5.2 Algorithm of Data Analysis

The algorithm of data analysis is shown in Fig.12. The functions of "getStartIndex()" and "getEndIndex()" are called to get the start index and end index of the transportation data collected in a smart card. The function "readOnePacket()" is used to read a packet of data with length of 8 bytes. The function "addRecord()" is used to add a record into a database. The functions "getStartingStation()", "getDestination()" and "getOperation" are used to get the information of a starting station, a destination and an operation of I/O from the data packet respectively.

```
Algorithm DataAnalysis{
    //the start index of the transportation data
    StartIndex = getStartIndex();
    //the end index of the transportation data
    EndIndex = getEndIndex();
    //data of start station
    Starting = null;
    //data of stop station
    Destination = null;
    //a set of operations data of I/O
    Operation = {};
    //initialize a data buffer
    Databuf = null;
    While (StartIndex < EndIndex){
        DataBuf = readOnePacket();
        If (it is a starting station){
            If (Starting is not null){
                addRecord(Starting, Destination, Operation);
                Starting = getStartingStation(DataBuf);
                Destination = null;
                Operation = {};
            }else{
                Starting = getStartingStation(DataBuf);
            }
        }else if (it is a stop station) {
            Destination = getDestination(DataBuf);
        }else if (it is an operation){
            Operation = Operation ∪ getOperation(DataBuf);
        }
        StartIndex = StartIndex + 8;
    }
}
```

Fig.12. Algorithm of data analysis

Therefore, a regular record only includes the information of a start station and a stop station. Once a record includes an I/O operation, then it is an illegal record because it means that I/O of the tank truck has been opened or closed in transit.

6 Implementation and Results

We have implemented the system according to the design mentioned above. VTR is the most important component in this system. The performance of VTR developed is shown in Table 5.

Table 5 Technical parameters of VTR

Items	Value
Working current (12 switch sensors)	≤80 mA
Maximum number of I/O monitored	12
Cumulative time error per year	≤ 60 Seconds
Speed of reading/writing a smart card	10 KBIT/S
Mean time to double failure	50000 Hours
Response time for alarm	≤ 1 Second

In this system, we use Microsoft SQL Server 2000 as the database server. The HMS is implemented by C/C++ language based on the RS232 driver program (which is based on the API of Window OS), the driver program of the IC card reader/writer and ADO components for the database operations. Note that the RS232 driver working with a RS485/RS232 converter is used to communicate with WDT via RS485 bus. Fig.13 is the main GUI of HMS, and Fig.14 is the output of transportation data.

The system has been applied to monitor and management the tank truck transportation in several provinces of China, such as Guangdong, Shandong, Fujian, Hainan and so on. Originally, the total loss of petroleum products transportation is about 0.2%. After using the system, the total loss of petroleum products decreases to about 0.1%, i.e., if the volume of petroleum products per month is 100,000tons, then the loss of petroleum products is reduced about 100tons per month.

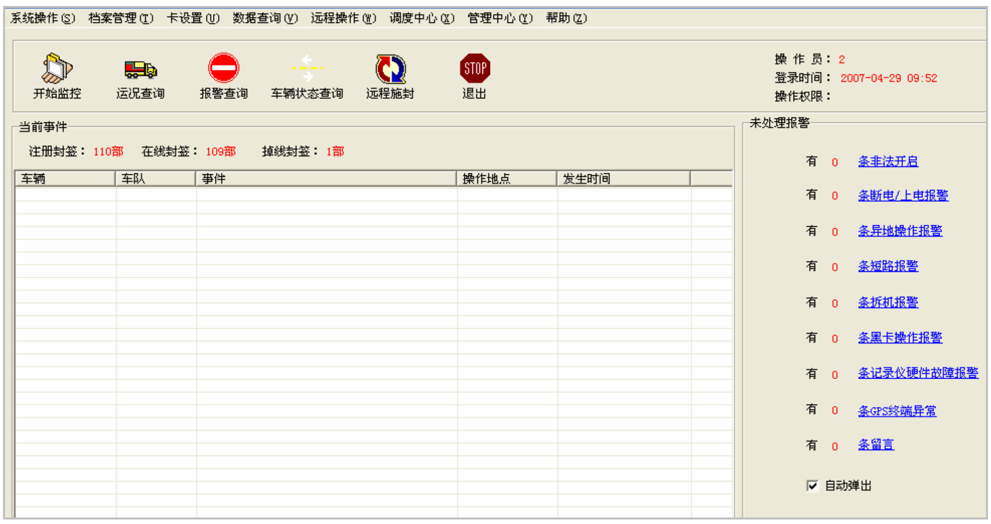

Fig.13. Main GUI of HMS

Fig.14. Output of transportation data

7 Conclusions

In this paper, an intelligent system based on smart card and wireless communication technologies is presented to monitor and manage the tank truck transportation. Compared with the traditional locking devices, it is not only a low-cost one-off investment, but also a precise integrated monitoring network, which can record the whole process of transportation. The system has been applied to monitor and management the tank truck transportation in several provinces of China. The system not only reduces the loss of petroleum products during the transportation efficiently, but also reduces the human cost by increasing the management efficiency. For future improvement, the system could be integrated with GPS so that it can monitor the tank trucks in more detail.

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