Design of non-contact fuel consumption real-time monitoring system for BDS positioning special vehicle

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Abstract. The fuel consumption measure is inaccurate and no real-time with the three-scale mete in the special vehicles, so the real-time fuel measurement system is developed with the technologies of ultrasonic sensing, single-chip microcontroller, BDS positioning and wireless communication. An ultrasonic oil level sensor is stuck on the bottom of each tank to detect the remaining oil of tanks accurately. It can avoid destroying the existing equipment structure. BDS positioning module is applied to monitor the location of vehicle. This technology is China complete autonomy. The special wireless transmission module and special network node are set up for transmitting the data of fuel consumption and position. It can guarantee the transmission secure and confidential. And a fuel consumption detection algorithm is studied with BDS measuring distance. The prototype is tested in four different road conditions. The error rate of oil detection on a highway with good conditions is 3.92%. And the measured fuel consumption value is close to the manufacturer's nominal value. The analysis of experimental data shows that the design of the detection system is reasonable and the fuel consumption detection algorithm is correct and reliable, and real-time fuel detection and positioning for the special vehicles can be realized.

1. Introduction
In order to carry the fuel as much as possible and avoid excessive fuel concentration in the special vehicles, the multiple fuel tanks are arranged in a corresponding space of the vehicle chassis. The adjacent fuel tanks are connected to each other by oil pipes, and all the tanks are divided into left groups and right group. Since the left and right group of fuel tanks are on the same level, a capacitance oil level sensor is fixed in the rear fuel tank of each group to detect the remaining total oil volume of the tanks. The result of detection is displayed in the meter dial for the driver[1,2]. But this meter dial can only display the proportion of remaining oil in the total tank volume, so there is a lack of precision. In the other way, the component of capacitance oil level sensor is easily jammed in the tank, which may cause the driver wrong judgment and become a common hidden danger of safe driving. At the same time, when the vehicle passes through the precipitous road, the float of capacitance oil level sensor will vibrate with the vehicle vibrating. This must lead to an inaccurate oil detection result [3]. Especially for military special vehicles with many irregular fuel tanks, the original oil detection device can lead to greater errors with the inclination of road and the bump of running. This will affect the work efficiency gravely. In addition, the accuracy of the action plan will be seriously restrict because
the headquarter can not grasp accurately the position, remaining fuel capacity and endurance of each special vehicle in real time.

In this paper, the fuel consumption real-time monitoring system is designed with the technologies of ultrasonic sensing, single-chip microcontroller, BDS positioning and wireless communication without damaging the existing equipment[4-6]. It can help the driver to sense the vehicle oil situation, and help the headquarter to remotely monitor the vehicle running state in real time, accurately and comprehensively.

2. General designing plan of the system
The non-contact real-time fuel consumption detection and location system for special vehicles is mainly composed of two parts. As shown in figure 1 and 2, One is the vehicle terminal for measuring fuel and positioning vehicle, the other is the remote monitoring center. The ultrasonic oil level sensor [7] is stuck on the bottom of the fuel tank to detect the remaining oil level of tanks accurately. The detection data of multiple fuel tanks and the positioning data of Beidou are calculated and controlled by the single-chip microcomputer. The results are displayed on the LCD panel installed in the cab in real time. At the same time, the data transmission is stored in the cloud server with wireless communication technology (such as GPRS) [8]. The number of command or dispatch center can monitor the running status of vehicles in real time, comprehensively and accurately with the PC, tablet and mobile phone client.

3. Design of vehicle terminal oil-measuring and positioning device
The working process of the oil consumption detection and location device is as follows. Several ultrasonic oil level sensors detect the remaining oil data of each tank separately. At the same time, Beidou positioning module collects the vehicle position information data. The data is processed by the single-chip microcomputer in the control circuit module. The result are displayed on the LCD display in real time and sent to the network server by the wireless transmission module and the special network node.

3.1. Hardware design
The hardware includes ultrasonic oil level sensor, Beidou positioning module, display module, wireless transmission and control module. The ultrasonic oil level sensor is stuck on the bottom of the outer surface of the vehicle fuel tank. The other modules are integrated in a small box and installed in the workbench area of the vehicle cab. The control circuit design is shown in figure 3.
ATmega32 MCU controls each device or module such as ultrasonic oil level sensor, wireless transmission, Beidou positioning and LCD display by the CD4052 chip which is a double 4-channel analog multiplexer/demultiplexer. And it communicates with one of the devices or modules separately. First, the TXD of ATmega32 MCU is extended to TXD1, TXD2, TXD3 and TXD4 by CD4052. Then, two groups of them, such as, TXD1, RXD1 and TXD2, RXD2 are converted TTL/CMOS input levels into RS232 levels by the MAX232, and can accept ±12V inputs. The conversion circuit convert RS232 into RS485 on the port of TXD1 and RXD1, and ATmega32 MCU can communicate with many of ultrasonic sensors. At the same time, TXD2 and RXD2 communicate directly with wireless transmission module. On the other hand, TXD3 and RXD3, TXD4 and RXD4 communicate with Beidou positioning module and LCD display respectively.

Figure 3. Structure diagram of the hardware design.

Figure 4. Flow chart of fuel consumption detection algorithm.
3.2. Software part design
The flow of software design is shown in figure 4. Firstly, the MCU and other modules are initialized, and the working mode of Beidou and ultrasonic sensor is set. Then it enters the circular work program. The data from the Beidou module are read and judged. If the value of the string "$BDRMC" from the received signal is true, that is to say, if $BDRMC = 1, the position data are temporarily stored, and the program continues to execute after the string is cleared. Otherwise the program returns to read the data from Beidou module again. Thirdly, the data from the ultrasonic sensor are read and processed, and the data of the total fuel and fuel consumption are gotten. Fourthly, the position information, fuel quantity and fuel consumption data are sent to the LCD display in real time. At the same time, the data is sent to wireless transmission module. The frequency of sending data is set to the vehicle driving distance $\Delta L$ (eg 2 kilometers, as set) or the time interval $\Delta t$ (eg, 10 minutes, as appropriate). The data are saved in the remote server and used for the client at any time. Finally, the return loop continues to receive and process data or exit the program.

4. Design of remote monitoring center
The remote monitoring center is used to receive information transmitted by the wireless data transmission network, and the information is processed and transmitted to the user, including the database server, the WEB server, and the user client. The database server and the WEB server access the wireless data transmission network through a dedicated line, and receive the transmitted data of fuel capacity and the vehicle positioning. And these data are processed and outputted to the user client. User clients include tablet computers, mobile phones and desktop computers. The self-developed monitoring software is installed to realize remotely management in the user client.

5. Experiments and results analysis
Based on the above design idea, a prototype of fuel consumption real-time monitoring system for BDS positioning special vehicle is developed, which is shown in figure 5. It is installed on a common special vehicles, and the experimental data are collected in executing the task. The nominal fuel consumption of special vehicles is 18 liters per 100 kilometers from the manufacturer in the experiment. It runs for 2 hours under the different road conditions around Pinggu District of Beijing. The remaining fuel of the tank is collected every 10 minutes. The number of actual fuel consumption is showed in table 1.

![Figure 5. Real-time fuel measurement prototype with BDS positioning.](image)

In order to verify the reliability of the prototype detection, the measured average fuel consumption is multiplied by the actual driving mileage in four different road conditions. The calculated fuel consumption is compared with the actual fuel consumption, and the error rate is obtained. These data are shown in table 2.
Table 1. Fuel consumption measured value in different road conditions (Litres / 100 kilometres).

| time (minute) | highway | common road | urban road | country road |
|--------------|---------|-------------|------------|--------------|
| 10           | 19.2    | 21.2        | 22.1       | 23.7         |
| 20           | 18.6    | 20.3        | 23.4       | 24.5         |
| 30           | 18.8    | 19.8        | 24.1       | 25.0         |
| 40           | 17.6    | 20.5        | 22.5       | 24.8         |
| 50           | 19.2    | 22.1        | 23.3       | 23.9         |
| 60           | 18.3    | 20.7        | 24.7       | 25.3         |
| 70           | 18.2    | 19.9        | 22.3       | 24.9         |
| 80           | 17.7    | 19.5        | 23.6       | 25.2         |
| 90           | 17.8    | 20.2        | 24.2       | 23.8         |
| 100          | 18.4    | 20.6        | 23.7       | 24.6         |
| 110          | 19.0    | 21.5        | 24.3       | 26.1         |
| 120          | 19.5    | 19.5        | 23.6       | 25.3         |
| **average fuel consumption** | **18.53** | **20.48** | **23.48** | **24.76** |

Table 2. Error rate of measuring fuel consumption relative to actual value.

| road conditions | mileage (km) | calculated fuel consumption ($10^{-2} \cdot km^{-1}$) | actual fuel consumption ($10^{-2} \cdot km^{-1}$) | error rate (%) |
|-----------------|--------------|-----------------------------------------------------|-------------------------------------------------|----------------|
| highway         | 136.4        | 93.7                                                | 74.3                                            | 87.6           |
| common road     | 25.30        | 19.19                                               | 17.45                                           | 21.69          |
| urban road      | 26.3         | 21.2                                                | 20.2                                            | 24.9           |
| country road    | -3.8         | -9.48                                               | -13.61                                          | -12.89         |

Analysis of the experimental data shows that:

1. On the highway, the measured fuel consumption data is relatively stable due to better road conditions, and the fuel consumption value is closest to the manufacturer’s standard value. On the other hand, the measured fuel consumption is slightly smaller than the actual fuel consumption, and the error rate is the smallest. Analysis reasons: According to the literature [9], the nominal fuel consumption of the manufacturer is usually measured at the same speed on a good road surface. On the highway, running speed is closest to the constant in the whole distance. But it inevitably reduces the speed for the toll stations or a few congested roads. While multiple brakes and speeds increase the fuel consumption. Therefore, it is consistent with the theoretical basis that the measured fuel consumption is close to and greater than the nominal value of the manufacturer, and the calculated fuel consumption is less than the actual consumption of oil.

2. On the common road and urban road, although the pavement texture is better, the vehicles run slowly for the narrow pavement and large crowded vehicles. Especially on urban roads, the frequent brake-starting operation increases fuel consumption for signal lights. Therefore, the measured average fuel consumption is greater than the manufacturer’s nominal value, and the measured fuel consumption is also less than the actual fuel consumption, and the error is relatively greater.

3. On country road, the texture of surface is poor, and the resistance from pavement is large. That results a great difference between the measured average fuel consumption data and the nominal value of the manufacturer. However, the people and cars in rural roads are few, which avoid the loss of fuel from the frequent brake-starting operation. Therefore, although the measured fuel consumption is also less than the actual fuel consumption, the error rate is lower than on the common road and urban roads.

6. Conclusion
In this paper, a prototype of real-time fuel consumption monitoring and positioning system for special vehicles is designed with the technology of ultrasonic sensor, single-chip microcontroller, Beidou positioning and wireless communication. For the structural characteristics and confidentiality requirements of special vehicles, the fuel monitoring system is studied with ultrasonic sensor to detect the remaining oil of tanks, Beidou module to locate vehicles and tactical or GPRS internet to transmit data. The design principle of hardware and software is discussed. And the experimental result of the prototype is analysed. All of these works underpinned the rationality and reliability of the system design. It can provide a novel idea for the scientific management and precision guarantees of vehicle.

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