Research on Safety Monitoring System for Dangerous Goods Transport Vehicles Based on Wireless Sensor Networks

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Abstract: In line with the safety management requirements for vehicles transporting dangerous goods, a variety of sensors targeting vehicle posture, acceleration, temperature, and more were selectively utilized to construct a wireless sensor monitoring network through sensor detection, Beidou satellite positioning, and remote communication technologies. This network processes and integrates signals from multiple sensors to perform real-time detection of the status of vehicles transporting dangerous goods on their journey. Detected hazardous states are transmitted to the control center and trigger alarms. This monitoring system not only prevents accidents from occurring but also facilitates timely and effective rescue operations in the event of an accident, thereby reducing losses.

Keywords: Wireless Sensor Networks; Dangerous Goods Transportation; Safety Monitoring; Routing Algorithms

1. Introduction

Hazardous chemicals are flammable, explosive, toxic, corrosive, radioactive and other characteristics, in the transport, handling and storage process, there are significant security risks. Road transportation management of dangerous goods is a worldwide difficult problem. In recent years, all kinds of major transportation accidents occur from time to time, which not only cause huge economic losses, but also lead to catastrophic destruction of ecological environment. Due to their unique physical and chemical properties, hazardous chemicals pose a significant risk of explosions, fires, poisoning, and other accidents if a vehicle collision, rollover, or chemical leak occurs under complex road transport conditions[1]. Currently, many domestic hazardous goods transportation companies employ monitoring methods such as video surveillance, positioning, and accompanying security personnel. However, these methods lack comprehensive monitoring and early warning capabilities for the vehicle's transportation state[2-3]. In accident analysis, we lack of real-time monitoring of vehicle posture, operation data and storage status of dangerous goods. For example: whether the dangerous goods transportation vehicle has the security hidden danger, its engine working condition, the oil road, the electric circuit, the brake and so on system is normal; Whether the driver information and dangerous goods information are recorded in real time, whether the tanks for storing and transporting dangerous goods leak, whether the valves of the tanks are normally locked, what the temperature and pressure state of the dangerous goods themselves are, and so on[4]. At present, the state information of dangerous goods transportation vehicles is still unforeseeable and unperceptible by the government, and there is a serious information blind area. It is difficult to obtain timely warnings before an accident occurs, and after an accident, it is challenging to promptly access various operational state data of the vehicle at the time of the accident, making it hard to conduct a scientific and accurate analysis of the causes of the accident[5].

In recent years, wireless sensor monitoring technology has been increasingly applied in the field of transportation safety monitoring[6]. This study aims to monitor the state of vehicles transporting hazardous chemicals, using wireless sensor networks as the primary monitoring technology, combined with Beidou satellite positioning technology, NB-IOT, and data fusion methods, to establish a real-time monitoring terminal system for the operational state of hazardous chemical vehicles[7]. This system can monitor the status data of hazardous chemical vehicles in real time, determine whether the vehicle is in a safe state, and plays a crucial role in enhancing the safety of hazardous chemical road transportation.

2. Safety Monitoring Requirements

2.1 Monitoring Subjects

Based on traffic accident statistics from the past decade, the primary causes of accidents involving the road transportation of hazardous materials have been identified as collisions and overturns[8]. Such accidents, mainly due to vehicle collisions or excessive turning angles leading to overturns, account for about 50% of all traffic accidents. Therefore, the focus of monitoring traffic accidents involving the transportation of hazardous materials is the real-time monitoring of vehicle posture information, including speed, tilt angle, and operating posture[9,10].

2.2 Monitoring Requirement

The safety monitoring system for vehicles transporting hazardous goods is a real-time monitoring system specifically designed for these vehicles. The system monitors the vehicle's speed, location, posture angle, and video information in real-time based on the vehicle's safe driving. On one hand, when the system detects a safety hazard in the transport of hazardous goods, it alerts the driver to stop for inspection and notifies the monitoring center. On the other hand, when an accident has occurred, the system stores the relevant information in a local computer and sends it to the monitoring center for timely accident rescue. The main monitoring requirements of the system include two parts[11]:

(1)Real-time sensor monitoring of vehicle operational status. This part requires sensors to work stably with strong anti-interference capabilities, providing timely feedback on vehicle and hazardous goods information.

(2)Accident early warning. If sensors detect any indicators exceeding threshold values, an immediate alarm should alert the driver, while the monitoring center should be able to send related warning information to the enterprise, safety supervisors, and other personnel. The local computer records the abnormal data during this period for later vehicle inspection.

3. System Design

3.1 Overall Structure

The safety monitoring system for vehicles transporting hazardous goods discussed in this paper aims to detect the status of the vehicle, with monitoring factors including posture, acceleration, and speed. Additionally, the system requires the establishment of local signal transmission and a local alarm mechanism[12]. It also integrates Beidou satellite positioning to monitor vehicle location and speed. The system comprises both hardware terminals and software analysis components. The hardware terminal integrates various detection sensors and sensing modules on the vehicle side, accessing the vehicle-mounted Beidou system through an expansion interface provided by the main control module. The system's wireless sensor network part is mainly responsible for all kinds of sensors can real-time and stable acquisition and transmission of data to monitor. This part is mainly to solve the selection of sensors and microprocessors, wireless data transmission, signal processing, data storage and power management, and so on.

(1) Sensor placement. Different types of sensors have different mounting positions according to the target parameters they measure. Choosing the right position to install the sensor can ensure that the measurement is true and reliable data.

(2) Wireless sensor networks. Because of the large number of sensors and the limited space of the vehicle, the measurement of the state parameters in the vehicle needs to use the wireless sensor network. The emphasis of this part is to ensure that the wireless sensor network can accurately and correctly determine the state parameters and wireless data transmission to the vehicle terminal.

The main structural design of the hardware terminal is shown in Figure 1:

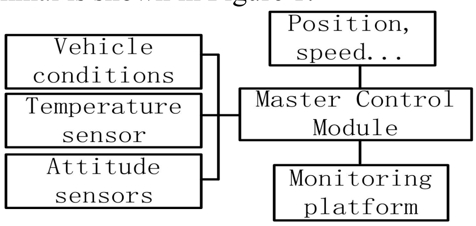

Figure 1. Basic Structure

3.2 Sensing Monitoring Factors

(1) Positioning, real-time speed, etc.: Based on latitude and longitude coordinate data collected

in real-time by the vehicle-mounted Beidou system module, it calculates real-time location, speed, and other data, with the monitoring platform providing data alerts. The speed monitoring alarm value range is set between 5 km/h and 80 km/h.

(2) Posture sensing monitoring: Monitors the vehicle's posture through posture sensors and pre-judges the vehicle's posture, issuing an alarm signal to alert the driver when there is a possibility of overturning. The first-level alarm value for posture monitoring is set at 25°, and the second-level pre-warning is set at 40°.

(3) Temperature sensor: The detection accuracy for ambient temperature is 0.5 ℃, with the alarm value set at 50℃.

(4) Vehicle condition data: Mainly includes ACC switch, fuel system, electrical circuit, and other conventional condition sensing data.

3.3 Posture Monitoring

Most vehicles transporting hazardous materials are prone to tipping over due to their high center of gravity and large volume and mass. Therefore, posture monitoring of vehicles transporting hazardous goods is a focal point of the system's monitoring, necessitating real-time monitoring of the vehicle's posture (tilt angle, speed, acceleration)[13]. The vehicle's posture primarily involves two parameters: the vehicle's lateral tilt angle and pitch angle, currently measured using inclinometers. Inclinometers can utilize three-axis or multi-axis accelerometers, calculating the tilt angle by measuring the components of gravitational acceleration on three axes[14]. However, due to significant fluctuations or vibrations during vehicle movement, using an accelerometer alone to measure angles can introduce errors, leading to considerable fluctuations in the data measured by the accelerometer. Considering the accelerometers available on the market, this system employs an integrated sensor that combines a 3-axis gyroscope with a 3-axis accelerometer, or a more precise nine-axis sensor can be used directly.

3.4 Data Processing

The status monitoring data of vehicles transporting hazardous goods come from multiple sensors, which may have different characteristics. Therefore, data fusion is employed to comprehensively process multi-source data. The process of data collection and processing involves monitoring the vehicle's status with multi-source sensors, converting it into electrical signals, transforming these into digital quantities through A/D conversion, and then filtering, amplifying, and integrating these data as the data source for fusion. After processing, feature extraction and data fusion are performed on the data, and finally, the vehicle's status is determined to be normal or abnormal based on the results of the fusion[15].The data collection and processing flowchart is shown in Figure 2.

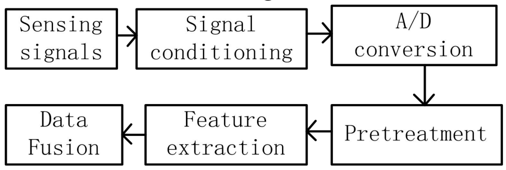

Figure 2. Data Processing Flowchart

3.5 Early Warning Process

Correct identification of hazardous states in vehicles transporting dangerous goods is essential for implementing safety warnings and vehicle control. Based on data fusion, reliable identification algorithms are needed to discern the levels of danger. Common state identification methods include wavelet transform, artificial neural networks, and cluster analysis[16]. During the state identification process, it's necessary to explore new or improved identification algorithms to enhance accuracy and reduce false positives. The process of identifying hazardous states in vehicles is illustrated in Figure 3.

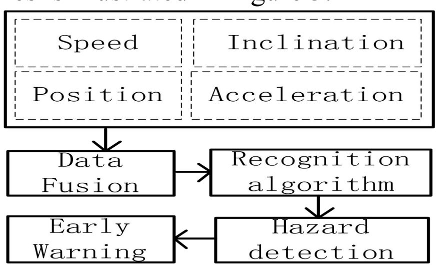

Figure 3. Posture Early Warning

3.6 Hardware Module

(1) The main control MCU is the STM32F103C8T6, with an ARM 32-bit Cortex-M3 CPU core, a maximum clock speed of 72MHz, 128K memory, operating voltage of DC 3.3V, 2 12-bit ADCs, and 2 I2C interfaces.

(2) Temperature and humidity are measured using the AM2301 capacitive digital

temperature and humidity sensor, which utilizes a capacitive humidity sensing element and standard digital single-bus output, with a collection accuracy of 16Bit, operating voltage of DC 3.5V~5V, and a minimum data reading interval of 2 seconds.

(3) The MQ-7 gas sensor is used, with the LM393 as the main control chip, operating voltage of DC 5V, dual signal output (analog output and TTL level output), and an analog output of 0~5V voltage.

(4) CO2 is measured using the SGP30 gas sensor, a metal oxide gas sensor with multiple sensing elements integrated on a single chip, capable of detecting CO2 and TVOC contents. It operates on a voltage of DC 1.8V~5V, with an I2C interface and a power consumption of 40mA.

(5) The MQ-135 gas sensor is used, with the LM393 and MQ135 gas sensing probe as the main control chips, operating voltage of DC 5V, dual signal output (analog output and TTL level output), and an analog output of 0~5V voltage, which increases with concentration levels, indicating high sensitivity to sulfides.

(6) The USR-NB700-BA, with dimensions of 82.58625mm and an SMA antenna, supports standard NB-IOT with bands B3, B5, B8, etc., and is compatible with telecom, mobile, and Unicom networks. It operates on a voltage of DC 5V~36V, with an RS232 interface and a baud rate of 115200.The communication module of the Internet of things is mainly responsible for sending the data detected by the sensors to the monitoring center stably and reliably. Because of the large amount of data, high transmission frequency, so how to ensure the timely and complete data transmission is a very important research content. In the test phase, we tried Bluetooth, WIFI, Zigbee and other communication methods. Bluetooth and WIFI methods are not convenient for long-distance running of vehicles, and require high resource and signal requirements. Zigbee is a more appropriate approach, but as the terminal can only be deployed in the cab, can not be deployed outside the vehicle. Therefore, considering the problem of terminal integration, the final decision to use the NB-IOT Internet of things card to send data, which has low power consumption, long-distance features, low cost, wireless nodes are very efficient at transmitting data.

(7)The WT901C digital attitude sensor, operating voltage of 3.3V~5V, measuring dimensions: 3D acceleration, angular velocity, angle, magnetic field. Data output frequency ranges from 0.1Hz to 200Hz, with a TTL serial port baud rate of 115200.

4. Hardware Terminal and Software System

4.1 Hardware Terminal

The condition monitoring data of dangerous vehicles comes from multi-sensors, which may have different characteristics, such as time-varying or non-time-varying, accurate or incomplete, reliable or unreliable, etc.. Therefore, data fusion is used to process multi-source data synthetically. In the context of transporting hazardous materials, due to the presence of shock absorbers and buffering devices at the bottom of the vehicle, the tilt angle of the vehicle tank is greater than that of the chassis. If the tilt angle of the vehicle chassis exceeds a certain threshold, it may indicate that the tank has already overturned. Therefore, positioning the sensors inside the vehicle rather than on the axle can help in early warning. In the experimental phase of this study, the hardware monitoring terminal was placed in the cabin where posture data relative to both the tank and the main axis of the vehicle are more stable, and it's also convenient for installation and maintenance without posing a threat to the safety of the tank, meeting the requirements of regulatory authorities. In the cabin, the main connection is to the vehicle power supply, which is connected to the sensor terminal through a 24/5V conversion circuit to ensure electrical safety. The hardware of the vehicle terminal is shown in Figure 4.

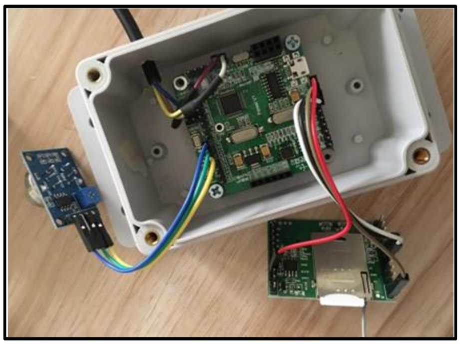

Figure 4. Hardware Physical Image

4.2 Software Monitoring System

The warning information from sensor data is mainly displayed through the sensor detection early warning system and alerts the monitoring personnel. The vehicle monitoring platform primarily serves as a centralized disposal platform for Beidou positioning data and sensor monitoring data of vehicles. Vehicle overspeeding, fatigued driving, video monitoring, and other features can be displayed through this platform. In the platform, it can clearly check the real-time status information of every dangerous goods transport vehicle, can see every alarm information, and can contact the vehicle escort personnel in time through the platform. The information of all dangerous goods vehicles can be stored for a long time, so that the driver or traffic accident can be analyzed and the real cause of the accident can be evaluated. The software operation interface of the system is shown in Figure 5.

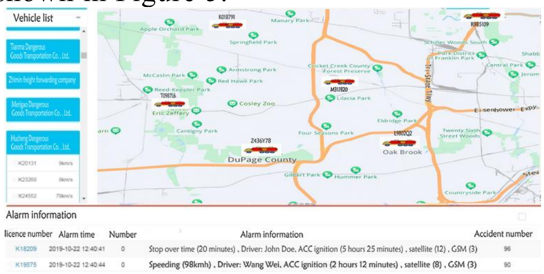

Figure 5. Monitoring Platform

5. Conclusion

To effectively curb the occurrence of accidents during the road transportation of hazardous materials, reduce the economic losses caused by such accidents, and diminish the impact on the environment and society, this study has utilized wireless sensor monitoring technology to establish a wireless monitoring network centered on vehicles transporting hazardous goods. It collects, transmits, analyzes, and provides early warnings for various sensor data related to the safe operation of the vehicle, achieving real-time monitoring of the vehicle's status during transit. The problem of the unforeseeable and unperceivable state of the dangerous goods transportation by road is solved, and the blind zone of the perception of the dangerous goods monitoring information is eliminated. The technology has been used in dangerous goods transportation enterprises, received praise from drivers and managers. The software and hardware of the system are still being optimized and updated. The application results show that the technology can improve the safety monitoring efficiency of dangerous goods vehicles, improve the ability of accident early warning and reduce the probability of accidents, it has good application value in reducing operation cost and so on.

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