Design of Expressway Safety Early Warning System Based on Internet of Things

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²The work was supported in part by the Featured Innovation Projects of Major Platforms and Scientific Research Projects in Guangdong in 2016(2016KTSCX187), and in part by the second batch of Industry-University Cooperation Collaborative Education Project in Higher Education Division of the Ministry of Education in 2017 (201702071042).

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Abstract. Aiming at the current situation of frequent accidents and slow rescue in the safety management of expressways in China, this paper integrates electronic, computer and Internet of Things technologies to form a self-organizing network through the routing nodes laid on the expressways, and constitutes an expressway safety warning system. At the same time, the mobile App, Web and PC monitoring platforms were developed and aggregated into the expressway traffic management center to realize real-time transmission and release of cross-platform alarm information. The test results show that the system can effectively reduce the incidence of accidents, especially secondary accidents, shorten the rescue time and improve the smooth flow rate of roads.

1. Introduction

Expressway is an important economic lifeline for the development of modern society. It has the characteristics of fast driving speed, large traffic volume, low transportation cost and safe driving [1]. It plays an important role in promoting national economic growth, improving people's quality of life and maintaining national security. According to statistics, as of the end of 2018, the total length of expressways had exceeded 140,000 kilometers, and the number of motor vehicles in the country had reached 327 million, including 240 million vehicles and 409 million motorists[2],[3]. However, China is one of the countries with the most traffic accidents in the world [4]. During the five years from 2010 to 2014, the total number of traffic accidents in the country totaled 1,029,735, an average of 205,947 per year, and most of the accidents occurred on expressways. The total number of traffic accidents was 711,199, with an average of 142,239.8 per year. The total number of traffic accident deaths was 304,671, including 223,431 deaths from car accidents, accounting for 73.33% of traffic accident deaths. According to other data, China's million car death rate was about 6.2%, 4-8 times that of developed countries[5]. The direct property damage caused by traffic accidents totalled 529 million yuan, of which the direct property loss of car accidents was 458 million yuan. The above data can be seen to enhance the importance and urgency of traffic safety management of expressways.

Traffic accidents on expressways generally have two outstanding features [6]-[8]. (i). Accidents caused by a single vehicle (such as accidents caused by car machinery failure, sudden flameout,
puncture, loss of control, sudden climate geography, etc.). (ii). The second accident of the rear vehicle was induced due to the occlusion of the warning information of the heavy and extraordinarily large accidents in front. According to research, if the driver takes measures 0.5s before he realizes the danger, it can reduce at least 60% of the rear-end collision accidents, or reduce the traffic accident of 30% of the head-on collisions. If the first 1s warning can occur in a traffic accident or unexpected situation, 90% of traffic accidents can be avoided[9]. Sudden weather disasters or traffic accidents may not be completely avoided, but we are fully capable of reducing or avoiding secondary traffic accidents caused by accidents. Therefore, how to reduce the occurrence of secondary traffic accidents by what methods and means has become a key problem that we urgently need to solve.

Therefore, this paper designs a expressway safety warning system. It realizes that when a natural disaster or traffic accident occurs on the expressway, the vehicle terminal of the preceding vehicle uses the wireless communication method to send alarm information to the rear vehicle and the expressway traffic management center in real time. In order to enable the rear vehicle to take measures such as deceleration, avoidance, and detour in time, and enable the traffic management center to understand the accident situation, organize rescue and release warning information, and improve the smooth flow rate of the road. The expressway safety early warning system is the nervous system of the entire expressway information communication network. It conducts large-scale, all-round and remote real-time monitoring of the expressway, improves the early warning mode of the expressway, accelerates the timely, accurate and efficient release of early warning information, and reduces the incidence of secondary accidents, thus improving the level of early warning management of expressway safety.

2. System design

2.1. System structure

The paper comprehensively uses the technology of vehicle networking, wireless sensor network, intelligent sensor detection, and designs a expressway safety warning system that can be used to reduce the incidence of secondary accidents, improve accident rescue speed, and remote road condition monitoring. The system is divided into four parts, namely the vehicle subsystem (terminal node), the routing node, the coordinator node and the control subsystem(PC). The schematic diagram of the expressway safety warning system is shown in Figure 1.

When a traffic accident occurs on the expressway or the vehicle has an unpredictable unexpected event that affects traffic safety, the onboard subsystem on the preceding vehicle may send an alarm message to the vehicle along the rear via a wireless communication network composed of the routing node subsystem. The vehicle subsystem interface of the rear vehicle immediately broadcasts the alarm information and displays the content of the accident in the interface. The content of the accident includes type of accident and accident distance, etc. At the same time, the routing node subsystem transmits the information to the expressway traffic management center. The PC terminal of the management center immediately gives a voice alarm reminder after receiving the accident information, and displays corresponding information on the management interface. The information content includes accident location, accident vehicle license plate number, accident occurrence time and accident type, etc. And then, the accident is passed through the map. The location is positioned so that relevant personnel can intuitively understand the accident situation, make emergency rescue measures in time, reduce casualties and property losses, and improve the smooth flow rate of the road. At the same time, the PC terminal uploads the accident information to the database of the cloud server. The web terminal, the mobile APP terminal and the WeChat public account can remotely access the database of the cloud server, and instantly update the interface data, so that the user can know the state of the expressway in time.
2.2. **Hardware system design**

The system hardware is mainly composed of three parts: the vehicle terminal module, the routing node module, and the coordinator node module. The vehicle terminal is composed of MCU, liquid crystal module, radio frequency module, gyro sensor module, GPS module, button module, and power module. The vehicle terminal is the source of the early warning information collection. The responsibility of the routing node is data forwarding and routing. Each routing node has a unique ID number, which is placed on the expressway in the order of the sequence and the specified distance, and can locate the specific location. The routing node can communicate with the vehicle terminal and the coordinator node, and finally send the information to the management center. The coordinator node communicates with the PC through the TTL to serial port, and sends the warning information to the gateway monitoring software. The system hardware design mainly follows the following standards: accurate and reliable operation, rapid response, strong anti-interference ability, moderate cost and good compatibility. The whole hardware system is more complicated. Some representative contents of this paper are introduced as follows.

2.2.1. **Vehicle terminal hardware design**

The vehicle-mounted terminal is a subsystem mounted on the vehicle. It is mainly responsible for collecting the current state of the vehicle. When the state is abnormal, the vehicle terminal transmits the warning information to the nearest routing node, and receives the early warning information that may exist in the preceding road segment from the information broadcast by the routing node. The vehicle terminal adopts IAP15F2K61S2 as the main control chip. It uses the results of the MPU6050 test by InvenSense of the United States as the basis for the collision of the vehicle. It uses the GPS module SKG09A to detect the current position of the vehicle. It uses the MQ2 sensor to detect the concentration of alcohol in the car. It uses the TGS2600 to detect the air quality inside the car. It uses nRF24L01+ RF communication module for wireless data transmission and reception. At the same time, it uses the LCD screen for information display, through the audio module for early warning information voice broadcast, set four buttons for function settings. Four buttons are used for alarms of different accident types, including natural disasters, traffic accidents, SOS, etc. The hardware design of the vehicle terminal is shown in Figure 2.
2.2.2. Routing node hardware design
The routing node is an important part of the system. It mainly completes the data receiving work of the vehicle terminal or the last routing node. When it receives the data frame, it is judged whether the data is valid. If it is valid, the data frame is sent to the next node. The routing node circuit design structure diagram is shown in Figure 3.

In this system, the routing node is powered by solar energy. In order to maximize the absorption rate of solar energy, the light intensity sensor BH1750FVI is added to the solar power supply module to detect the direct solar angle. And the steering gear is used to control the direction of the solar light to the maximum. The mechanical structure of the solar direct angle tracking device is shown in Figure 4. If the routing node is located in the tunnel, it is supplied by the tunnel lighting system power supply through the buck current limiting circuit.

2.3. Software design
There are seven main components of the expressway security warning system: vehicle terminal program, routing node program, gateway program, cloud server program, mobile APP program, Web-side program and WeChat public number program. The system software design is based on the system hardware. On the basis of the existing hardware of the system, how to make the system function perfect, reliable performance and stable operation is the key to the program design.

2.3.1. Early warning information data frame format and distance calculation formula
Since the system uses the self-organizing wireless network to transmit early warning information, the first problem to be solved is how to implement wireless networking, and secondly, to determine the early warning information data frame format [10]. The system adopts a networking technology based on dynamic and static combination of wireless radio frequency modules. Static routing nodes form a chain network. Broadcast communication is used between static routing nodes and dynamic in-vehicle terminals. A detailed paper on how to use the nRF24L01+ wireless networking has been published
The format of the early warning information data frame adopted by the system is shown in Table 1. The data frame includes the latitude and longitude information of the GPS detection, the routing node ID number, the license plate number, the driving mode, the type of the accident. When receiving the data from the front warning information through the wireless ad hoc network, the vehicle terminal will parse the data packet, and calculate the distance $S$ between the in-vehicle terminal and the vehicle terminal of the accident vehicle, as in equation (1). At the same time, it also alerts the driver by voice announcements and display warning messages.

$$S = R \times \arccos(\cos \frac{\pi y_1}{180} \cos \frac{\pi y_2}{180} \cos \frac{\pi (x_1 - x_2)}{180} + \sin \frac{\pi y_1}{180} \sin \frac{\pi y_2}{180})$$

The earth radius $R=6370996.81$m. $(x_1, y_1)$, $(x_2, y_2)$ are the GPS positioning coordinates of the two vehicles respectively.

### Table 1. 32-byte data frame format definition used by the system

| Byte No. | [0] | [1-2] | [3] | [4] | [5] | [6]-[9] | [10-14] | [15-31] |
|----------|-----|-------|-----|-----|-----|---------|----------|---------|
| definition | Routing node ID | Way of sending | Type of accident | Driving mode | Accident routing node ID | Info. note | License plate number | Latitude and longitude |

2.3.2. *Vehicle terminal programming*

The vehicle terminal has functions such as gyroscope attitude detection, GPS positioning, button module, voice alarm, and display. When it starts to work normally, the MCU of the vehicle terminal system first initializes each function module program, and then the system continuously queries whether to receive the warning information broadcast by the routing node without interruption. When the warning message is received, the voice alarm is immediately displayed and displayed. Then continue to check if there is an event. The event can be triggered by the driver's manual button or the car body automatically detects the collision trigger. The event interrupt handler is called immediately when the event is triggered, and the warning information is sent to the routing node. If there is no trigger event, it will loop through the query to see if there is an event trigger. The program flow chart is shown in Figure 5.

2.3.3. *Routing node programming*

Chain networking is used between routing nodes. The Routing node mainly completes three functions.

(i). receiving the data frame sent by the nearby vehicle terminal or the previous node.

(ii). processing the received data frame and forwarding it to the next routing node, and broadcasting the notification to the in-vehicle terminal within the coverage.

(iii). detecting the direct sunlight angle, and correspondingly adjust the PV panel angle to optimize solar absorption.

As a passer, the routing node serves as the main role of the link. When receiving the information sent by the previous routing node or the vehicle terminal, the routing node immediately enters the interrupt to determine whether the data frame is valid. If it is valid, the corresponding frame instruction is sent to the next node. If no information is received or an error message is received, the routing node is always receiving the query status. The program flow chart of the routing node sending and receiving data is shown in Figure 6.

Solar charging provides energy for the continuous operation of routing nodes, so solar panels must be fully energized. Solar tracking devices enable solar panels to maximize energy for the system. The MCU timing triggers the steering gear to drive the light sensing module to detect the direct sunlight angle, and adjusts the angle of the photovoltaic panel rotation through the direct angle. The subroutine flow chart of direct sunlight angle tracking device is shown in Figure 7.
2.3.4. Coordinator programming
The coordinator is mainly responsible for data communication between the gateway and the wireless ad hoc network. The coordinator performs data communication with the gateway through the serial port on the one hand, and performs data communication with the routing node (coordinator) through the radio frequency module on the other hand. Therefore, the coordinator works in two ways. First is to receive the data packet sent by the routing node through the radio frequency module, and then pass the received data to the gateway through the serial port. Second, the information sent by the gateway is forwarded to the wireless ad hoc network through the radio frequency module. The coordinator program flow chart is shown in Figure 8.

2.3.5. Gateway programming
As an information processing and monitoring center, the gateway program development uses Qt as the development environment, C++ as the back-end processing language, and My-SQL on the cloud server as the database and accesses it in the SQL language. It is mainly responsible for the record function of accident information, as well as querying and displaying the type of accident, accident
license plate number, accident time, accident location, etc. on the Qt-GUI interface. The gateway mainly performs four functions.

(i). Data transmission and reception with the coordinator.

(ii). Data interaction with My-SQL cloud database, including insertion and query of accident warning information.

(iii). Realize the positioning function of the accident vehicle on Baidu map through Baidu's javascript API interface.

(iv). Accident information display interface and human-computer interaction function.

The information processing and monitoring function structure of the gateway system is shown in Figure 9.

![Subroutine flow chart of direct sunlight angle tracking device](image1)

![Coordinator program flow chart](image2)

2.3.6. Programming of other terminal platforms

In order to facilitate the user's real-time query of expressway traffic information, the system also develops the mobile APP, Web and WeChat public accounts, which mainly implement the following four functions:

(i). Index function: Users can query the accident information in the My-SQL database by time range or keyword, and display it on the interface.

(ii). Statistical chart display: The accident will be performed by executing different SQL statements to filter out different records and by recording the number of daily accidents, and drawing them into statistical charts for statistics and analysis.

(iii). Statistical table display: The content of the statistical table is displayed by acquiring the data information of the database of the remote server.
(iv). Map location: When clicking to view the map, the web terminal or mobile terminal will index the coordinates of the corresponding information of the database, and combine with the Baidu map obtained by the javascript API to locate, providing a more intuitive and visual interface to the user.

The mobile platform function implementation process is shown in Figure 10.

3. Test results and analysis
Since it has not been officially put into commercial operation, this test is carried out on a road section with a length of about 4km. First, a routing node is set on the roadside. The effective communication distance of nRF24L01+ can reach 2km. To enhance the fault tolerance of the communication subnet, set up one routing node every 800m. One of the three cars was equipped with an in-vehicle terminal for testing. The whole experiment consisted of 5 routing nodes, 3 car terminals, 1 coordinator, 1 mobile phone and 2 PCs (one with gateway software and one with web server).

The three test cars are distributed in different positions on the 4km road. When the vehicle-side button on the front car is manually pressed to simulate the accident information, the vehicle-side terminal will package the accident information and send it to the routing node within the coverage of the RF signal. The routing node along the way sends the accident information frame to the back and
broadcasts it, and finally transmits it to the PC. All vehicles in the rear can receive the accident information from the preceding vehicle through the broadcast information of the nearby routing node to achieve the early warning effect. At the same time, the remote PC, mobile App, and Web can see information such as the vehicle and location of the accident. The test results are shown in Figure 11, Figure 12 and Figure 13.

Figure 11. Vehicle terminal of rear vehicle displays accident information.

Figure 12. PC monitoring interface. (a) Accident scene photo. (b) Accident map location display. "001" "002" "003" "004" in the figure(b) are the routing node ID.
Figure 13. Web-side statistical analysis interface.
(a) Data analysis of traffic accidents in the past week.  (b) Statistical analysis.

The test results show that through the system, the accident information transmission of the expressway network section can be quickly realized, and the rear vehicle can be promptly warned. The remote monitoring terminal (PC) can also view high-speed traffic information in real time. The expressway traffic management center can timely rescue and divert traffic according to the early warning information when necessary, reduce the hazard of the accident and increase the expressway traffic rate.

4. Conclusion
In view of the current situation of frequent traffic accidents in expressway safety management in China, combined with existing technologies such as electronics, computers, Internet of Things and Internet of Vehicles, the vehicles on the expressway are formed into self-organizing networks through routing nodes laid along the expressway. It constitutes a expressway safety warning system, real-time transmission and release of accident warning information, and is summarized into the expressway traffic management center. The test results show that the system can realize the real-time reflection of any time along the expressway, any place, any accident, and the state of any vehicle to the traffic management center to achieve 24-hour road condition monitoring. It can effectively reduce the incidence of secondary traffic accidents, shorten the rescue time, improve the smooth flow rate of the road.
The project will continue to study and realize the integration of the vehicle terminal and the driving recorder to improve the practicability of the system and achieve the corresponding social and economic benefits.

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