A Vehicle-to-Infrastructure Wireless Communication System Based on ZigBee

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ABSTRACT: In order to acquire the real-time attitude information in the performance test of vehicle, alleviate the pressure of transportation caused by economic development and reduce the number of traffic accidents, we propose a vehicle-to-infrastructure wireless communication system based on ZigBee in this paper. The STM32 micro controller is used as the MCU of in-vehicle terminal to process the data obtained from inertial sensors, including the acceleration, angular acceleration, position, etc. Then the data is transmitted to the infrastructure unit or ground test station via ZigBee wireless network node. CRC check-sum is used to improve data accuracy and an user interface is designed. Finally, monitoring the driving state of the vehicle is achieved. The real vehicle test results show that the system is stable and reliable.

KEYWORDS: ZigBee; wireless communication; vehicle-to-infrastructure

1 INSTRUCTION

With the rapid development of economy, people's living standards continue to improve and the amount of the vehicle ownership has increased year by year. Vehicle becomes an important traffic tool, which results the more and more serious traffic congestion and traffic accidents. This is not only a waste of time and economic losses, but also a danger to personal safety. However, it is increasingly limited to improve the traffic problem by relying on traffic safety education, broadening the road, limiting the vehicle travel and other traditional ways. Therefore, the intelligent transportation technology has become the focus of global attention. If the driver can get information of the position, velocity, acceleration and driving direction of nearby vehicles in real time, the corresponding measures can be taken in time to avoid the accident. Even only 1s in advance on the driver safety warning, we can reduce 50 percent to 90 percent of accidents. In this background, by means of vehicle-to-vehicle (V2V)\textsuperscript{[1,2]} and vehicle-to-infrastructure(V2I)\textsuperscript{[3,4]} communication to get state of moving vehicles, and then we can provide warning information to the driver in advance to improve traffic safety. This becomes a focus topic of intelligent transportation\textsuperscript{[5,6]}.

The ZigBee\textsuperscript{[7]} wireless communication technology is applied in the field of intelligent transportation system in this system, which can realize the vehicle-to-infrastructure communication. The vehicles can be automatic networking and broadcast their driving state incessantly when the vehicles travel to a certain range of distance. In that case the driver can make a prejudgment on the moving of the nearby vehicles, so as to maintain a proper speed and distance and reduce traffic accidents.

The system can also contribute to the investigation of the accident. The data written in the SD card can help to analysis the responsibility and the cause of traffic accidents. It also can be applied to the performance test of vehicle. Through the wireless transmission of vehicle status in real time and backup, it can facilitate the data analysis in the future and get rid of the cumbersome field wiring and improve efficiency.

2 SYSTEM DESIGN

2.1 Hardware design of the system

The V2I wireless communication system based on ZigBee consists of two parts: in-vehicle unit and infrastructure unit. The in-vehicle unit is installed in the interior of the vehicle, which takes STM32 micro controller as the core, inertial measurement unit to get the attitude information such as the acceleration of three directions and angular in the process of
moving. ZigBee wireless communication module is used for wireless communication between in-vehicle data acquisition system and infrastructure terminal device. The SD card is used to save the data in real time, and the touch panel to display the current driving status. The infrastructure unit can be installed in the test site in the performance test of vehicle, the roadside telegraph pole and lamp pole, used to receive and forward the data transmitted from the in-vehicle unit. The hardware design principle of the in-vehicle unit, as shown in Figure 1.

![Figure 1. The principle of hardware design.](image)

For the demand of fast response, high reliability, strong processing power, simple structure, low power consumption for the in-vehicle data acquisition system, the STM32F103ZET6 is used as the main control chip of our system, which is produced by ST company and based on Cortex-M3 kernel, arm V7 architecture 32-bit microprocessor. It is applicable to the data processing of this system due to the high code density, low prices, low power consumption, fast processing speed, stable performance and excellent real-time performance characteristics.

The wireless transmission of data using ZigBee technology, which is a new short-range wireless communication technology, working in the ISM band. The ZigBee protocol is based on PHY (physical layer) and MAC (medium access control layer) defined in IEEE 802.15.4, combined with the NWK (network layer), APS (application support sublayer), APL (application layer) technical specification defined by ZigBee alliance. It uses the direct sequence spread spectrum technology, which has the characteristic of anti-co-frequency interference. Compared with other short distance communication technology such as Bluetooth, WiFi, ZigBee technology is more accessible with its low power consumption, low complexity, low cost, long transmission distance, large network capacity, reliable communication and the advantages of the flexible working frequency. Therefore, it is suitable for the in-vehicle short distance communication system.

The data collected is always required to backup in the computer or use the computer to process data in later period. SD card, with its large capacity, high speed, simple interface has been rapidly development. Therefore, in order to facilitate the analysis and storage of the data in the process of driving, the attitude data collected by JY901 module is sent to the SD card via USART2.

This system uses the high precision inertial navigation module (JY-901) to measure the attitude of the vehicle, which is integrated with high precision gyroscope, accelerometer and geomagnetic sensor. It uses high performance microprocessor and advanced dynamic calculation and Kalman filter algorithm, which can quickly and accurately solve the real-time motion attitude of the vehicle body. Its measurement precision is 0.01 degrees and its stability is extremely high.

### 2.2 Software design of the system

The software design of sending or receiving terminal device is shown in Figure 2. At first, our system initializes each module, and then STM32 micro controller reads the vehicle attitude data collected from inertial sensors by usart2. After data verification only to retain the correct data packets and save the attitude data in the SD card. Finally, the ZigBee module sends the data out, then the receiving terminal device saves the data after validation.

![Figure 2. The software design of sending terminal device.](image)
Vehicle-to-infrastructure communication test scene is shown in Figure 3. \( d_0 \) represents the distance between infrastructure unit and motor vehicle lane, \( d \) is the distance between vehicles and infrastructure unit. The transmission distance is 10m in this test. According to the scene, the point to point vehicle-to-infrastructure communication platform based on ZigBee is set up. The test was done on the open campus, including static test and dynamic test. Set the data of packet loss rate less than 5% as the effective transmission of data.

Figure 3. The test scene of V2I communication.

(1) When the in-vehicle unit and the infrastructure unit are stationary, test 10 groups of sending and receiving data of each different distance from 10 meters to more distance. Test results show that the packet loss rate in the range of 200m is near 0.

(2) We have tested 10 times in turn when the vehicle passed the infrastructure unit at the speed of 10km/h, 15km/h, 20km/h, 25km/h...45km/h. The data in the figure below is the average of the 10 times. The data saved in the SD card of in-vehicle sending module and roadside receiving module are compared to calculate the packet loss rate. Then the packet loss rate and transmission distance at different speeds are calculated.

Figure 4. The relationship between speed and packet loss rate.

The figure 1 shows that the packet loss rate increases with the increase of the vehicle speed. When the vehicle speed reaches a certain threshold, the packet loss rate rises rapidly, even reaching 100%, that is, the network cannot be built. The figure 2 shows that the transmission distance becomes shorter with the increase of the speed. When the vehicle speed exceeds a certain value, the transmission distance becomes 0, that is, the network cannot be built.

There are many factors that affect the communication performance, including speed, the Doppler effect, the transmission distance, the height of antenna, the environment, the interference of other ways of communication, etc. And the electromagnetic interference in the process of the experiment, including the interference of engine ignition coil, switch equipment, motor and other electronic equipment interference, etc.

4 MEASURES OF IMPROVEMENT

4.1 The optimization of Z-STACK

By modifying the program of network layer and MAC layer in Z-STACK to change the specific detail of the networking process. The main factors which affect the network delay of vehicle communication module mainly includes channel scanning time, the response time of waiting for the coordinator sending a connection replay, scanning the channel number and beacon request times of terminal device. Reducing the time consumption of these four processes can improve the network delay. By setting the entrance parameters of MAC_MlmeSetReq function in the protocol stack can shorten the response time of the coordinator waiting to send a connection replay. The setting of this value needs to be tested. Finally, we selected 2 as the response time value. In addition, Z-STACK
also has the corresponding macro definition of beacon request number of terminal device.

4.2 Anti-interference and reliability design of the hardware system

The basic anti-interference idea of system hardware is to take different measures to destroy the basic factors that lead to the interference, such as the interference source, receiving circuit sensitive to interference, coupling channel of interference source and receiving circuit.

(1) It can effectively suppress the noise interference from the digital circuit to the analog circuit by separating the wiring from the analog and digital, and using the inductor to connect the analog ground and digital ground at the power source.

(2) The power supply pin is connected with the decoupling capacitor, which can shorten the flow path of the switch current, and greatly reduce the voltage drop of the conductor.

(3) As far as possible to reduce the loop area in the process of PCB board wiring to reduce the induced noise. Try to avoid the acute angle shaped line to reduce the high frequency noise emission.

5 CONCLUSIONS

The test data shows that the V2I communication system based on ZigBee is feasible in lower speed in the process of data transmission. It can be used in the low speed traffic in the city and vehicle performance test with low cost and high reliability, to avoid all kinds of complicated wiring work. This system is conducive to the research of active safety. Due to the constraints of the actual experimental conditions, there are still a lot of measures to improve and perfect our system.

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