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Research on Vehicle Safety Warning System Based on Data Fusion

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Abstract: Vehicle dynamic safety warning system based on data fusion is researched and designed in this study. Dynamic information of vehicle, road and environment can be collected in real time. By analyzing and processing these data, active safety warning information is achieved for individual vehicle on different work condition. Security characteristic parameter, road conditions and traffic meteorological information can be detected automatically by the vehicle dynamic security supervision system. Active warning and supervision of comprehensive vehicle safety performance are achieved. The warning system owns the function of data acquisition, operation, wireless data transmission, information distribution and parameter preserving. Warning information is transferred by wireless network in real time. Research work in this study is applied to road traffic control area. This vehicle warning system is of value to removing incipient fault of running vehicle, improving reliability, rational maintaining and proper inspection.

Key words: Data fusion, vehicle, safety, road, traffic

INTRODUCTION

On highway and urban road, vehicle running conditions, road conditions, rain, snow, fog and other weather deterioration are important factors that cause the traffic accident and road jam. Therefore, the detection and analysis of vehicle conditions, road conditions and weather situation play the important role on the safety of urban and highway traffic. Active prevention measures have a positive effect on avoiding accidents. Adaptive safety warning system which react to vehicle speed, turning radius and road condition, lowered collision and property damage claims on cars tested. Forward collision avoidance systems equipped with an alarm, automated braking or some combination thereof also worked well in preventing front-to-rear collisions.

Active safety warning system of vehicles is discussed in this study. The alarm system developed by this study is able to collect vehicle dynamic information and urban road dynamic traffic information in real time through the wireless communication network. Aiming at generating active safety warning information for different vehicle conditions quickly, multi-level data fusion is implemented. The early-warning information is released to vehicle owners through variable information board, cellular phone, broadcast and etc. This kind of system is capable of coordinating driver, vehicle, road and environment comprehensively. Driver and vehicle monitoring system may monitor both driver and vehicle behavior. Information can be gathered from driver input and control of the vehicles lateral position and speed, such as acceleration steering wheel movement and lane position. The research and development of the safety and pre-warning system based on multi-layer data fusion which provide an important guarantee for safe driving on highway and urban road.

VEHICLE DYNAMICS INFORMATION ACQUISITION AND PROCESSING

Vehicle dynamic operating parameters directly indicate the security status of the vehicle. Correspondingly, they are the basis data of the urban road vehicle active safety warning systems. Dynamic information acquisition and processing is implemented by vehicle-mounted terminals as shown in Fig. 1. The

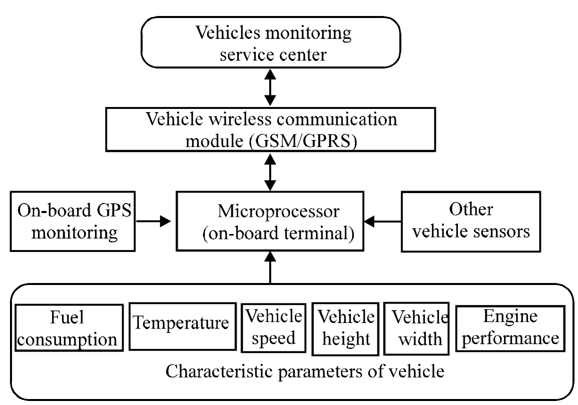

Fig. 1: Structural diagram of vehicle safety warning system

vehicle-mounted terminal plays the important linkage role. Upwardly, it unites vehicles monitoring service center through the vehicle wireless communication network (Navet *et al*., 2005). Downwardly, it unites vehicle master controller interface through the network bus. By collecting and processing automotive sensor, output signal and vehicle dynamics information, vehicle breakdowns are analyzed and judged accurately.

Vehicle detection unit is composed of signal acquisition system, control system, communication system and external device, etc. Its main technical content includes the following parts.

- It collects data of automotive engines, chassis, electrical equipment and automotive electronic equipment output in real time including characteristic parameters of vehicle running performance and the output of vehicle-mounted electronic device such as the vehicle height, vehicle width, fuel consumption, temperature, speed, engine and chassis, etc
- It receives active safety alert information generated by the center server through vehicle wireless communication module (GSM/GPRS) such as the recommendation driving speed, wind speed, direction of wind, air temperature, visibility, ice, snow, fog, the road situation, the bridge weight limit and the tunnel height limit etc
- Vehicle dynamic information is uploaded to the central server in real time including the output data of vehicle operating parameters and on-board electronic equipment
- It provides interactive interface including LCD module and keyboard input module. In order to accurately provide the decision-making basis for making the safety early warning, drivers can enter additional information related vehicles. The display screen also has early warning information release function

Vehicle working performance parameters of the electrical equipment is detected by a series of sensors. These internal operating parameters indicate the safety status of the vehicle. So, they are the basic data of active safety warning systems. In addition to the on-board electrical equipment, its working state parameters can be collected through the equipment I/O interface (Wang and Chen, 2006). Embedded on-board terminal is the product developed by this project. It is responsible for getting parameters of operating vehicle and electrical equipment. The on-board terminal will upload these parameters to the vehicle supervision service center. Therefore, these data are written into the internal memory of active safety and early-warning system (Cena and Valenzano, 1997).

ROAD DYNAMIC TRAFFIC PARAMETERS COLLECTING AND PROCESSING

Road dynamic traffic parameter is a general concept including road environment information and road traffic information, traffic meteorological information, etc. This study focuses on the vehicle safety most related to road conditions and meteorological conditions. Traffic services and road maintenance services are provided through the combination of the weather and road detection. Over climate changes will affect the normal operation of the traffic flow.

When average or instantaneous horizontal wind speed is too high, driving stability will be damaged. So, traffic safety accident is easy to cause. The surface water of road can also affect the driving stability. Small and medium-range weather condition can be acquired by the local weather forecast. Other valuable information can be achieved by installing conventional meteorological detector on the road.

Dynamic road traffic parameters acquisition and processing were completed by two sub-modules. The main technical content of sub-modules includes the following parts.

- **Weather conditions acquisition and processing sub-module:** This module has the function of processing wind speed, wind direction, air temperature, visibility, water depth and other data that have effect on traffic safety
- **Road conditions acquisition and processing sub-module:** This module has the function of processing road situation, road weight limit, bridge weight limit, tunnel height limit and other data that have effect on vehicle safety. After processing, these two sub-modules upload the data to the vehicle supervision service center in real time. These data are seemed as the basis information for active safety alarm system. The function and structure of each module are shown in Fig. 2.

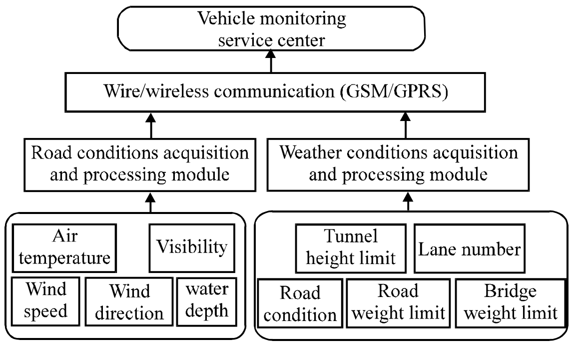

Fig. 2: Dynamic road traffic parameters acquisition and processing

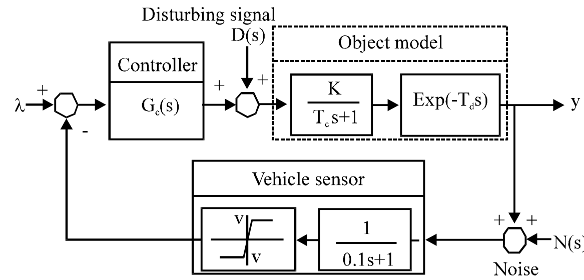

Fig. 3: Closed loop control system

MULTI-MODE AND MULTI-LEVEL DATA FUSION ALGORITHM OF THE VEHICLE MONITORING CENTRE

If an exception occurs during driving, exceptions and information related to vehicle characteristics can be transmitted over the wireless network to the vehicle monitoring center. After collecting the original parameters, monitoring center server processing modules calculate various performance and indicators that are benefit for safety warning (Cao, 2007). Vehicle monitoring service center is equivalent to the brain center of the vehicle active safety warning system. It is responsible for the collection, processing, analysis of the vehicle information, road dynamic traffic parameters and the effect of meteorological environmental information. It can automatically generate the active safety warning information for a variety of vehicle speed, road conditions and environment. According to the actual needs of the vehicle, the warning information is sent to the vehicle terminal or mobile phone via., a wireless communication network. It can also release the alarm information on variable information road panels through wired network. By releasing alarm information in different time, different weather, different road, this system provides effective help and support for safe driving and path planning.

Actual vehicle is a complicated nonlinear system which includes intake air dynamic, fuel dynamic, exhaust gas dynamic and sensor dynamic. These parameters vary along with the change of exotic environment and work condition. It is hard to build perfect mathematic model of the nonlinear engine system (Yousefi, 2005). We utilize the linear model to describe the complex automotive engine system in the actual design process. The structure of closed loop system is illustrated in Fig. 3.

The fast precision control of vehicle has been implemented through ECU and actuator which mounted on the vehicle body. Based on micro controller, this system can response external signal quickly. Kinds of sensor output have been gathered. The logical decision and ratiocination are completed (Fredriksson, 2002). The parameters of controller device are perfectly regulated. This system can be used as a platform for developing many kinds of automotive engine control methods (Clarke, 1998).

An application of H-infinity robust design to monitoring and control system is developed. The safety warning system must respond rapidly and accurately even though the system encounters large parameter changes in the operational environment. Robustness is the main issue in the attempt to realize a warning system satisfying basic requirement for drivability and other vehicle performance. The feedback control system configuration is presented in Eq. 1. The notation Gc(s) indicates the compensator transfer function to be determined so as to establish the control specifications for both robust stability and transient characteristics. In the H-infinity robust control theory, such a compensator can be realized by determining the proper transfer function Gc(s) satisfying as follows:

$$\left\| \begin{bmatrix} W_s(1+HG_0G_c)^{-1} \\ W_m HG_0G_c(1+HG_0G_c)^{-1} \end{bmatrix} \right\|_\infty < 1 \tag{1}$$

Data fusion means an approach to information extraction spontaneously adopted in several domains. Data fusion is the process of integration of multiple data and knowledge representing the same real-world object into a consistent, accurate and useful representation. Multiple sensors would provide redundancy which would enable the dynamic safety warning system to provide information in case of partial failure, data loss from one sensor. Data fusion exploits the synergy offered by the information originating from various sources. Data fusion allows formalizing the combination of these measurements as well as to monitor the quality of information in the course of the fusion process.

Combination of additional independent and/or redundant data usually results into an improvement of the results.

Define p(A) as the probability of occurrence of an event A and p(A, B) as the probability of occurrence of two events A and B. Then, the conditional probability of occurrence of A given that the event B has already occurred and can be related as follows:

$$p(A, B) = p(A|B)\, p(B)$$

$$\sum_{i=1}^{n} p(A_i) = 1$$

We will notice that because p(A, B) = p(B, A):

$$p(B, A) = p(B|A)p(A)$$

$$p(A|B) = p(B|A)\, p(A)/p(B)$$

The above relation can also be written as follows:

$$p(A|B) = \frac{p(B|A)p(A)}{\sum_{i=1}^{n} p(B|A_i)p(A_i)}$$

The above equation is known as Bayes rule (Raol, 2009). From Bayes rule, we obtain the following general application rule for the independent likelihood pool:

$$p(O_j|D_1 \cap D_2 \cap \cdots \cap D_k) = \frac{p(O_j)p(D_1|O_j)\cdots p(D_k|O_j)}{\sum_{i=1}^{n} p(O_i)p(D_1|O_i)\cdots p(D_k|O_i)}$$

O_1, O_2...,O_n are defined as incompatible events. Multiple sensors are used to get target instructions. Under the condition of a given real goal j, we can get an update joint probability based on multi-sensor specification. The probability is shown as:

$$p(O_i|D_1 \cap D_2 \cap \ldots \cap D_n)$$

Most of safety warning systems use radar sensors, laser sensors or video sensors. Regardless of the type of sensor, these systems are unable to operate in good condition with failures on actuators, sensors or on both of them. The safety warning system is capable of judging the relative position and speed of other vehicles. That data can be used to automatically adjust the speed of the vehicle's that equipped with adaptive cruise control. Active warning system can also pulse the brakes or activate the power steering to keep the vehicle in safe condition. Warning system uses sensors to scan for objects in front of the vehicle and they can apply the brakes if an object is detected. One sensor is capable of determining whether there are any obstructions in front of the vehicle.

The detection probability of one sensor on vehicle is 0.87. The probability of false alarm is 0.06. Three sensors are respectively given three independent judgment (1, 1, 0). The results are fusion by Bayes fusion method. The detection probability of the safety warning system is shown as follows:

$$p(O_1|D_1 \cap D_2 \cap D_3) = \frac{0.5\times 0.87\times 0.87\times (1-0.87)}{0.5\times 0.87\times 0.87\times (1-0.87) + 0.5\times 0.05\times 0.05\times 0.95} = 0.976$$

If the independent judgment is (0,0,1). The detection probability of the safety warning system is shown as follows:

$$p(O_1|D_1 \cap D_2 \cap D_3) = \frac{0.5\times (1-0.87)\times (1-0.87)\times 0.87}{0.5\times (1-0.87)\times (1-0.87)\times 0.87 + 0.5\times 0.95\times 0.95\times 0.05} = 0.246$$

Base on the data fusion result, this system will provide a warning to the driver if there is an obstruction.

The output waveform of oxygen sensor signal and intake manifold absolute pressure sensor signal is shown in Fig. 4 and 5. Figure 4 shows two sensors waveform under the steady state condition. The engine speed is 2000 rpm. The intake manifold vacuum is 0.032 MPa.

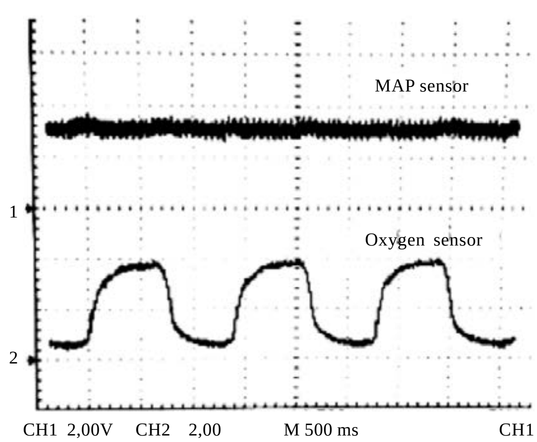

Fig. 4: Output of manifold absolute pressure sensor and oxygen sensor (engine speed:2000 rpm, intake manifold vacuum:0.032 MPa)

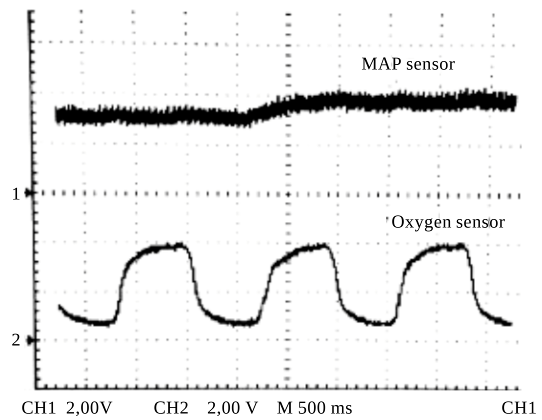

Fig. 5: Output of manifold absolute pressure sensor and oxygen sensor (engine speed:2000 rpm, intake manifold vacuum:0.032 MPa→0.02 MPa)

Fig. 6: Hardware of controller

Figure 5 shows the output of sensors when the intake manifold vacuum ranges from 0.032-0.02 MPa. We can find the waveform variation of oxygen sensor is very slight when increasing the throttle opening. When the working condition of vehicle changes, the performance is still kept in good status. Experimental results show algorithm is robust to resist normal and variable working condition.

The electronic control unit of safety warning system is designed. The hardware of controller is shown in Fig. 6. The safety warning system consists of sensors, actuators, controller and signal processing circuit. The core of the electronic control unit is a high-speed, 16-bit microcontroller MC68HC912D60A. It has 60k bytes of flash EEPROM, 2K bytes of RAM, 1K bytes of EEPROM, 8-channel and 10-bit AD converter. It is sufficient to the real-time vehicle control. Signal acquisition part comprises the sensor signal processing circuit and the AD converter component. The ECU can be divided into some module circuits such as power supply circuit, sensor preprocessing circuit, protective isolation circuit, microcontroller interface circuit and actuator driving circuit.

The design of software is based on a multiple task real-time system. The air fuel control and exhaust gas recirculation control are properly switched, scheduled and coordinated by CPU (Sasaki and Sawada, 1998). Resources such as sensor signals and control variables can be shared. Thus this real-time system is stable and reliable. It is superior to the foreground-background processing system.

CONCLUSION

With the increasing consciousness for environmental protection and safety consciousness throughout the world, now a days the research and development of vehicle monitoring become an important subject. Based on the practical research project of data fusion, study on vehicle dynamic safety warning system has been done. Research works in this study have important theory meaning and engineering application value for vehicle safety, effective energy utilization, exhaust contamination reduction, energy conservation and environmental protection. Safety characteristic parameter, road conditions and traffic meteorological information can be detected automaticly by the vehicle dynamic safety supervision system. Active warning and supervision of comprehensive vehicle safety performance are achieved. This system owns the function of data acquisition, operation, wireless data transmission, information distribution, parameter preserving and safety signs. Design scheme is practiceable and reasonable. This system works stably and reliably.

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