A FlexRay/CAN Vehicle Communication Network for an Anti-Lock Braking System Based on X-by-Wire Technology

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Abstract

In this study, a new FlexRay vehicle communication network was integrated with the current mainstream network CAN. The FlexRay network was connected by a hybrid topology to a brake-by-wire node to implement an x-by-wire control system.

The CarSim software was combined with LabVIEW and interface cards to construct and test the active safety of a simulated car. An anti-lock braking system (ABS) node based on FlexRay communication transmitted vehicle speed through the FlexRay network immediately. Moreover, a FlexRay-monitoring node monitored the ABS simultaneously. ABS data were transferred to the CAN network via a FlexRay/CAN gateway.

Furthermore, an ABS-monitoring application was developed for an Android phone using Bluetooth to transmit data on both wheel speeds and brake slip values.

Keywords: ABS, FlexRay, X-by-Wire

1. Introduction

There are numerous motivations for the determination of FlexRay as the standard communication system. New x-by-wire functions have stringent requirements for determinism and short latencies. In addition, upcoming active safety functions are characterized by large volumes of data traffic.

The FlexRay system is a communication system developed for the next generation of automobiles by a consortium founded in 2000 by Daimler-Chrysler, BMW, Motorola, and NXP Semiconductors. The FlexRay communication protocol has been designed for high data transmission rates (10 Mbps) required by advanced automobile control systems.

Thus, FlexRay can be considered a global standard for connecting electronic control units (ECUs) in the automotive industry. Despite this global commitment to FlexRay and the vision to use it as an enabler of drive-by-wire solutions, it is currently only used for driver assistance, comfort, and power-train functions. The X-by-wire technology for automobile safety application has been rapidly developed and improved [2][3].

The concept of x-by-wire systems has been commonly applied in the throttle-by-wire and brake-by-wire systems of vehicular applications. The most familiar feature of brake-by-wire technology is the anti-lock braking system (ABS), regarded as standard equipment in automotive safety [4][5]. The ABS is an essential device that can automatically adjust the brake force [6] to control the wheel slip ratio within a predetermined range during the braking process and prevent a wheel lock. In addition, an ABS improves steering ability and stability, and reduces braking distance.

The vehicle dynamics software CarSim has been used as a simulation platform, and Matlab/Simulink and LabVIEW have been applied to build a model of an ABS controller [7-9]. In this study, CarSim software was used in combination with LabVIEW and interface cards to build a model of an ABS controller, and to construct and test the active safety of a simulated car.

Because data need to be transferred between different networks, a gateway system allows separate protocols to engage with one another [10][11]. Consequently, a gateway system was developed to exchange information between CAN and FlexRay networks for distributed control and intelligent FlexRay safety monitoring.

This study used an MC9S12XF512 CPU (Freescale) as the core microprocessor of all ECU nodes. A FlexRay/CAN gateway was used to implement system functions and communication interfaces, and to further complete the FlexRay network of a vehicular x-by-wire system [12].
This study proposes a FlexRay/CAN vehicle communication network for an ABS, which was developed to implement a vehicular x-by-wire system by using the FlexRay protocol as the backbone for data communication. In addition, an ABS-monitoring application was developed for an Android phone using Bluetooth to transmit user-friendly data, such as wheel speeds and brake slip values.

2. General Introduction to the System Design

2.1. The FlexRay Network

FlexRay is a new deterministic, fault-tolerant, high-speed bus system that can satisfy the requirements for future in-car control applications. Moreover, FlexRay is a heterogeneous protocol consisting of static (ST) and dynamic (DYN) segments. The communication cycle is the fundamental element of the media-access scheme within FlexRay, as illustrated in Figure 1. In an ST segment, a high degree of determinism can be provided using a time-division multiple access (TDMA) scheme. An ST segment is composed of several slots. In contrast, a DYN segment can be used to enhance the flexibility of communication. A DYN segment is composed of several mini-slots.

FlexRay combines the advantages of time-triggered and event-triggered communication protocols, promoting determinism and flexibility. FlexRay also supports redundant channels for fault-tolerant communication. Currently, FlexRay is expected to enable various automotive applications, such as active safety, passive safety, power-train management, integrated chassis control, and driver-assistance systems [13].

In the DYN segment of the communication cycle, each device transfers event-triggered messages prioritized by its frame ID. The frame ID is used for controlling media access. The length of these segments is also defined in the configuration [1].

2.2. The Anti-Lock Braking System

An ABS is an automobile safety system that allows the wheels of a motor vehicle to maintain tractive contact with the road surface according to driver inputs when braking, preventing the wheels from locking (ceasing rotation) and avoiding uncontrolled skidding. It is an automated system that uses the principles of threshold braking and cadence braking, methods practiced by skillful drivers using previous braking systems. It applies these techniques at a much faster rate and with better control than a driver could manage.

In general, an ABS offers improved vehicle control and reduces stopping distances on dry and slippery surfaces. On loose surfaces such as gravel or a snow-covered pavement, an ABS can increase the braking distance and improve vehicle control substantially.

An ABS comprises four main components: speed sensors, valves, a pump, and a controller [14][15]. The speed sensors, which are located on each wheel, provide speed information. An ABS needs a method of determining when a wheel is about to lock. A valve is in the brake line of each brake
controlled by an ABS. When an ABS operates the brake valves, the brake lines lose pressure. A pump re-pressurizes the system.

The ABS controller is an ECU-type unit in the car that receives information from each wheel speed sensor. If a wheel loses traction, the signal is sent to the controller. The controller then limits the braking force and activates the ABS modulator, which switches the braking valves on and off.

As shown in Figure 2, the fundamental principles of the ABS can be expressed in a graph showing the relationships among the slip rate, brake force, and cornering force. The calculation formula of slip rate is

\[
\text{Slip rate} = \frac{(\text{Vehicle speed} - \text{Wheel speed})}{(\text{Vehicle speed})} \times 100 \text{ (%)}
\]

The continuous line in the graph represents the relationship between the slip rate and brake force. It is commonly known as a µ-S curve, in which µ, a coefficient of friction between the tires and the road surface, is used in place of the brake force. This curve shows that the brake force is largest when the slip rate is between 10% and 20%; that is, the wheels are slipping at 10% to 20% of the wheel velocity.

The braking distance is the shortest at this time. If the wheels are locked (100% slip rate) because of having applied the brake with excessive force, the brake force is reduced, resulting in a longer braking distance.

![Figure 2. Relationships between braking force, cornering force, and slip rate](image)

In addition, as shown in Figure 3, the relationship between the slip rate and friction coefficient varies on differing road conditions, such as dry, wet, snow-covered, and ice-covered roads.

Hence, this paper introduces the process of creating a FlexRay/CAN vehicle communication network for an ABS. The platform consists of x-by-wire nodes (steer-by-wire, throttle-by-wire, and brake-by-wire nodes), a FlexRay/CAN gateway, and a FlexRay-monitoring node, as shown in Figure 4.

The FlexRay network, using single-channel transmission at a transmission rate of 10 Mbps, was connected by hybrid topology. The throttle-by-wire, steer-by-wire, and brake-by-wire nodes were designed and implemented using an x-by-wire control. In addition, the FlexRay/CAN gateway was used to combine the FlexRay and CAN networks, and it was connected to a Bluetooth module (HL-MD08R-C2, Hotlife) to implement a Bluetooth transport.

The CAN network, set at a transmission rate of 500 Kbps, contained an LCD dashboard and lamp control nodes. A CAN network-monitoring application was used on an Android platform to obtain data on the CAN network. The ABS-monitoring application was designed using a Bluetooth transmission. A remote-control car was employed to simulate vehicle movements.
2.3. The FlexRay Communication Network

A high-speed FlexRay network with real-time and high safety features was developed with careful consideration of improving the safety rates, transmission rates, and cost control. Drive-by-wire control was implemented using throttle-by-wire, steer-by-wire, and brake-by-wire nodes. A FlexRay/CAN gateway was used to connect FlexRay and CAN networks to conduct signal transition.
The configuration of parameters was complex in the FlexRay network. To implement data transmission easily, the FlexRay network was established using Designer Pro V4.3 to conduct parameter settings and configurations of data frames on each node.

The system was developed based on an intelligent FlexRay safety-monitoring platform [12]. This study focused only on a brake-by-wire node design.

A brake-by-wire node has two MCUs to implement brake control and ABS control in CarSim software. MCU A is responsible for calculating the wheel speed, and MCU B is responsible for brake control and FlexRay communication. A block diagram of a brake-by-wire node is shown in Figure 5. The physical diagram of a brake-by-wire node is shown in Figure 5.

![Figure 5. A brake-by-wire (ABS) node hardware block diagram](image)

2.4. ABS-Monitoring Application Design

In this study, an ABS-monitoring application was developed on an Android phone (HTC, Wildfire A3333).

The Bluetooth communication protocol was used to implement monitoring of ABS data. To implement Bluetooth transmission, users must complete four steps: 1) Open Bluetooth communication, 2) Search Bluetooth device, 3) Connect Bluetooth device, and 4) Transport Bluetooth data. The screen display of the ABS-monitoring application is shown in Figure 6. The upper four values display the wheel velocity, and the lower four values display the brake slip value. From left to right, LF represents a left front wheel, RF represents a right front wheel, LR represents a left rear wheel, and RR represents a right rear wheel.
2.5. CarSim Software Design

CarSim software was adopted to execute dynamic vehicle simulation. In this study, parameters were configured for a hatchback car with a wheel sized 15 in. and an engine power of 200 kW. LabVIEW software was applied to build an ABS controller model, and was connected with CarSim software to calculate ABS values. The import and export parameters must be configured by the user.

The import parameters include the brake pressures of all four wheels and the opening degree of the throttle valve. The export parameters include the speed of each wheel, the vehicle speed, and the pressure of the brake master cylinder.

After setting the parameters, the CarSim software module was combined with the LabVIEW RT program to implement throttle, brake, and ABS control, as shown in Figure 7.

Using the PWM function of the interface card, NI PXI 6602, the throttle-by-wire node executes throttle control, whereas the brake-by-wire node executes brake control, as shown in Figure 8.

![Figure 6. The ABS-monitoring application displayed on an Android phone screen](image)

![Figure 7. The LabVIEW RT Program combined with the CarSim software module](image)
Using the D/A converter channel of the interface card, NI PXI 6722, the wheel speed and vehicle speed were outputs of the LabVIEW RT program after reading the CarSim module, as shown in Figure 9.

Through the I/O output function of the interface card, NI PXI 6722, the brake-by-wire node executed the ABS control, as shown in Figure 10.

The LabVIEW RT Program Panel is shown in Figure 11. The upper panel shows the wheel speed and vehicle speed in the left diagram and brake pressures in the right diagram. The lower panel shows the brake pressure, the opening degree of the throttle, and the ABS control status from left to right.

2.6. ABS Control Design

The main purpose of an ABS is to avoid a wheel lock when braking, thereby raising the force of friction and reducing the braking distance. The optimal force of friction can be achieved by employing a slip rate of between 10% and 30% [15].

In this study, a wheel slip control algorithm was adopted and implemented. First, two wheel speed and vehicle speed parameters were calculated to obtain slip rate values by using (1).

After the wheel slip rate was calculated, the minimum slip rate and maximum slip rate were set at approximately 10% and 30%, respectively. Depending on the wheel slip rate, the algorithm has three switches:

1. wheel slip rate < minimum slip rate: increasing brake pressure
2. minimum slip rate < wheel slip rate < max slip rate: maintaining brake pressure
3. wheel slip rate < max slip rate: decreasing brake pressure
Figure 9. The wheel speed and vehicle speed are outputs of the LabVIEW RT program.

Figure 10. The input ABS control signal of the LabVIEW RT Program.
3. Experiment

The experiment where the FlexRay/CAN vehicle communication network was investigated for an ABS consisted of ABS brake testing and brake-by-wire testing. An enhanced capture timer (ECT) of MC9S12XF512 (Freescale) was used to capture the speed of the wheels from the wheel speed sensor of the brake-by-wire (ABS) node and to control the solenoid valve using general purpose input/output (GPIO). The ECT was also used to test whether the wheel was close to locking when brake pressure was applied. Once a wheel was about to lock, the brake-by-wire (ABS) node controlled the solenoid valve to conduct brake pressure distribution and to determine the optimal braking efficiency.

A physical diagram of the current system is presented in Figure 12.
3.1. ABS Brake Testing

The brake pedal was applied at a vehicle speed of 150 km/h to implement ABS brake testing. Figure 13 (no ABS) and Figure 14 (ABS) show wheel and vehicle speeds during the braking process at a high friction coefficient. Figure 15 (no ABS) and Figure 16 (ABS) show wheel and vehicle speeds during the braking process at a low friction coefficient.

Therefore, a vehicle equipped with an ABS provides superior brake performance. The ABS test results are shown in Table 1.

<table>
<thead>
<tr>
<th></th>
<th>High Friction Coefficient</th>
<th>Low Friction Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>no ABS</td>
<td>6.05s</td>
<td>11.85s</td>
</tr>
<tr>
<td>ABS</td>
<td>5.55s</td>
<td>11.35s</td>
</tr>
</tbody>
</table>

3.2. Brake-by-Wire Testing

A brake-by-wire node uses the static segment of the communication cycle to transport data in a FlexRay network. The FlexRay-Monitoring node was used to monitor data from the brake-by-wire node. Figure 17 shows the console screen display when the vehicle speed was 150 km/h.
Figure 13. Wheel speed and vehicle speeds during the braking process at a high friction coefficient (no ABS)

Figure 14. Wheel and vehicle speeds during the braking process at a high friction coefficient (with ABS)

Figure 15. Wheel and vehicle speeds during the braking process at a low friction coefficient (no ABS)
Figure 16. Wheel and vehicle speeds during the braking process at a low friction coefficient (with ABS).

Figure 17. The FlexRay-monitoring node displayed on the console screen when the vehicle speed was set to 150 km/h.

The ABS-monitoring application when the vehicle speed was set to 150 km/h, and its display is shown in Figure 18.
The brake pedal was applied to execute brake testing. Because the front wheel was slower than the rear wheel, the brake force of the front wheel needed to be larger than that of the rear wheel. The display of the ABS-monitoring application is shown in Figure 19.

Figure 18. The ABS-monitoring application displayed on an Android phone with the vehicle speed set to 150km/h

Figure 19. The FlexRay monitoring node displayed on the console screen when the brake pedal was applied

The display of the ABS-monitoring application when the brake pedal was applied is shown in Figure 20.
4. Conclusion

This paper proposed the design of a FlexRay/CAN vehicle communication network for an ABS based on x-by-wire. The FlexRay-monitoring node simultaneously monitored and acquired FlexRay network data. The FlexRay/CAN Gateway transmitted ABS data to an Android phone through the Bluetooth protocol, and converted data between FlexRay and CAN networks.

Furthermore, the ABS-monitoring application was developed for an Android phone to show wheel speeds and brake pressures in a user-friendly display. Using the CAN network-monitoring application on an Android platform, a user can obtain communication data on the CAN bus more conveniently because of easy operation and high portability.

In summary, a complete ABS controller based on x-by-wire control was implemented in this paper. In the future, this system can provide an experimental environment for subsequent researchers to execute the analysis of FlexRay parameters and related tests.

5. Acknowledgment

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6. References


Figure 20. The ABS-monitoring application displayed on an Android phone when the brake pedal was applied.


