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Priority-based Multi-level Monitoring of Signal Integrity in a Distributed Powertrain Control System

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Abstract: With the increasing numbers and importance of Electronic Control Units (ECUs) in modern automobiles, there is a need to monitor system and signal integrity to enable desired system behavior. Among the various signals in a vehicle, those associated with torque commands must be prioritized over others while preserving signal integrity as they have a large impact on meeting the powertrain performance and safety requirements. In the case of a Hybrid Electric Vehicle (HEV), there are multiple torque actuators (Motor, ICE) that need to be controlled and failure to do so can damage the powertrain. Hence in all cases, the torque requested by the driver should be the same as the sum of the outputs of all the torque actuators and within the limits, which is referred to as ensuring Torque Security (TS). In this paper, we propose a priority-based multi-level signal integrity monitoring technique in which we divide controller signals into different groups and monitor them by making use of performance counters. The proposed technique was implemented and verified using Hardware-In-the-Loop (HIL) testing as a part of the Colorado State University (CSU) EcoCAR3 advanced vehicle technology competition.

Keywords: Torque security, Powertrain control, Hybrid Electric Vehicle (HEV), Signal integrity, Powertrain Control System

1. INTRODUCTION

As the number of Electronic Control Units (ECUs) in modern vehicles increases, the in-vehicle control and communication network has become highly complex. This problem is perhaps more acute in the case of a Hybrid Electric Vehicle (HEV) as there are a greater number of electrical components such as motors, batteries, and DC-DC converters, than in conventional vehicles. In most modern HEVs and conventional vehicles, Controller Area Network (CAN) is the most widely used communication protocol because of its simplicity, low cost, noise immunity and ease of implementation. However, it suffers from low bandwidth, poor security, message delays etc. as discussed in (Kleberger et al. 2011). The typical communication system in a HEV is shown in figure 1. The driver inputs are sent to the supervisory controller via CAN, and it sends the appropriate signals to all the other local controllers via CAN messages. If there are multiple nodes connected to the same CAN channel, then the network congestion increases which leads to many issues such as signal delay, loss of signal integrity, jitter, and other failures as mentioned in (Tindell et al. 1994). All of these communication system limitations must be detected and remedied to avoid catastrophic vehicle-level malfunction.

Comprehensively monitoring the integrity of 100% of the signals in the vehicle would greatly increase the required bandwidth of the communication system. To avoid this naïve approach to signal integrity monitoring, we seek in this study to monitor signal integrity for only those signals that are of importance to vehicle safety and performance. In particular, we focus on monitoring the signal integrity of torque-related signals because of their importance in preserving the safety and performance of the vehicles.

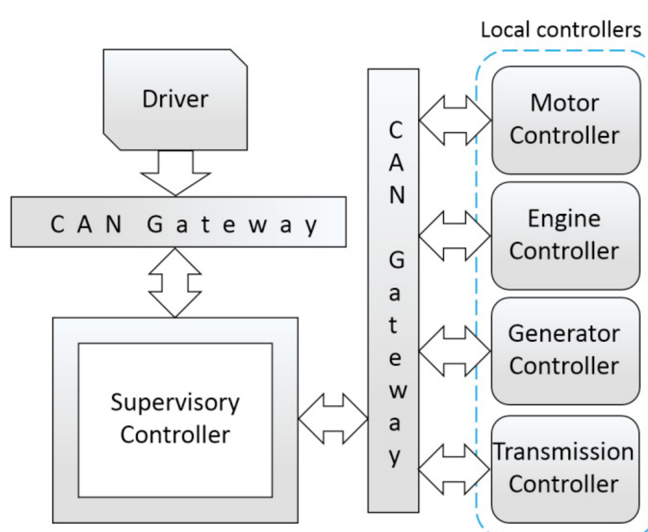

Fig. 1. Typical communication system in a HEV

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2. RELATED WORK

Various techniques have been proposed to protect the signal integrity in CAN and other busses. (Nilsson, D.K et al. 2008) present a delayed data authentication technique using the KASUMI encryption algorithm in CBC-MAC (Cipher Block Chaining- Message Authentication Code) mode to generate a 64-bit compound MAC for a group of four messages, which is further divided into four 16-bit MACs and each of them is stored in the 16-bit CRC (Cyclic Redundancy Check) field of the next four CAN messages. This technique assures message integrity, but suffers significant delay as the first four messages are validated by comparing the generated MAC with the received MAC in the CRC field of the next four messages. Furthermore, the delay in receiving the second group of messages adds to the overall delay, limiting this algorithm's usefulness in time-critical powertrain control applications.

(Sundaram et al. 2006) discuss different controller integrity techniques and propose asymmetric and extended asymmetric controller strategies. In these strategies an auxiliary controller is used to check the integrity of the primary controller. Some of these techniques have synchronization hardships, size and power overhead, and also encounter overhead in making changes to the existing network. (Buur. H et al. 2013) introduce a signal integrity technique in which the original signal, along with a redundant signal in encrypted form is sent in the same message. This signal is validated by comparing the original signal and decrypted redundant signal. The main limitation of this technique is that the bandwidth requirements get doubled, leading to a high bus load. Also, encrypting and decrypting signals can incur high computational overhead in the system.

The motivation for our research is to come up with a signal integrity technique that helps to improve the signal integrity in the CSU EcoCAR3 project without incurring significant overhead on the controller while trying to minimize bus traffic. In this paper we introduce a priority based, multi-level signal integrity technique in which, error tolerance for different signals are set according to the order of priority and are monitored using performance counters. The rest of the paper is organized as follows: In section 3, the proposed technique is presented in detail and in section 4 and 5, the experimental setup and results are discussed. In section 6, this method is illustrated by performing analysis on bus parameters and vehicle performance and section 7 presents our conclusions.

3. PRIORITY BASED MULTI-LEVEL SIGNAL INTEGRITY TECHNIQUE

An illustration of the proposed technique is shown in figure 2. In the first step, we divide different controller signals into different groups based on their criticality. In the next step, messages are transmitted and a handshake signal is sent from the supervisory controller to the local controller to which the torque command is sent. To monitor the signal integrity we make use of performance counters in the supervisory controller and set a threshold for the number of negative acknowledgements that command the local controller to discard the message and take appropriate remediation actions. If the number of negative acknowledgements exceed the threshold, the vehicle is moved into one of the limp modes depending on the criticality level of the failed signal, otherwise the vehicle operates normally.

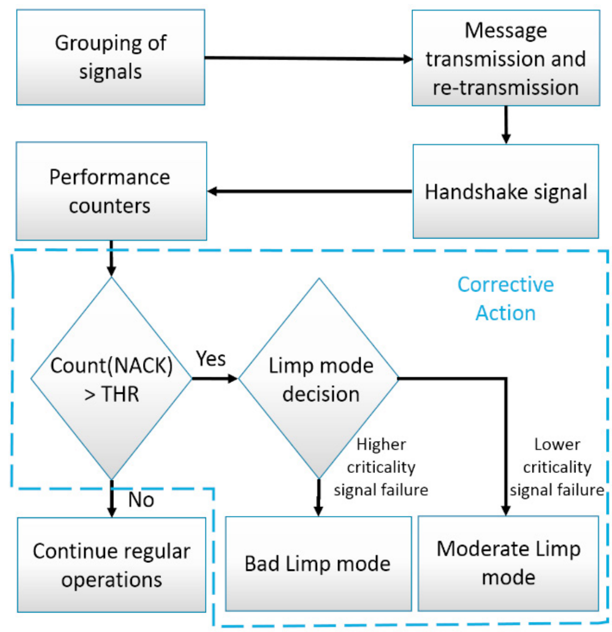

Fig. 2. Flow chart of proposed technique. (NACK = Negative Acknowledgement, THR = Threshold)

3.1 Grouping of torque related signals

In this subsection, we discuss how different torque–related signals are considered from various components in the vehicle and grouped together based on their criticality. Each group is assigned different levels of criticality with level-1 being the most critical group and level-4 being the lowest. The signals in different levels impact the vehicle performance and safety in different ways. Detection of failures in signal integrity should therefore be handled differently at each level of criticality. Thus, the limit of fault tolerance varies from level to level as discussed in the next sub-section. Table 1 shows the grouping of different controller signals and their criticality levels. Inefficient grouping of signals can have a negative impact on the safety and performance of the vehicle.

Table 1. Grouping of signals and their criticality levels

Criticality level	Signals
Level- 1	Physical brake request, Motor regen request
Level- 2	Motor torque request, Engine torque request, Acceleration pedal position sensors (A & B)
Level- 3	PRNDL, Ignition
Level- 4	Infotainment