

An Investigation into Multi-Core Architectures to Improve a Processing Performance of the Unified Chassis Control Algorithms

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ABSTRACT

This paper describes an investigation into multi-core processing architecture for implementation of a Unified Chassis Control (UCC) algorithm. The multi-core architecture is suggested to reduce the operating load and maximization of the reliability to improve of the UCC system performance. For the purpose of this study, the proposed multi-core architecture supports distributed control with analytical and physical redundancy capabilities. In this paper, the UCC algorithm embedded in electronic control unit (ECU) is comprised of three parts; a supervisor, a main controller, and fault detection/ isolation/ tolerance control (FDI/FTC). An ECU is configured by three processors, and a control area network (CAN) is also implemented for hardware-in-the-loop (HILS) evaluation. Two types of multi-core architectures such as distributed processing, and triple voting are implemented to investigate the performance and reliability. A vehicle simulator and brake HILS are used to evaluate the proposed multi-core architectures. From the test results, it is shown that all of the proposed multi-core systems have better performance and improved reliability compared with the single-core system.

1. INTRODUCTION

Recently, according to the interest for passive and active safety systems, research for integrated systems, which consists of Electronic Stability Control (ESC), and Active Front Steering (AFS), is progressed with activity [1]. These

systems have various names, e.g. Vehicle Dynamic Management (VDM), Global Chassis Control (GCC), Unified Chassis Control (UCC) and so on. Many papers have been published in the area of these integrated systems, such as VDM and UCC [2]. However, there are problems of overall stability, reliability, and enhanced operation capability of the systems. For example, the VDM approach is made up of two types of electronic control units (ECUs). One has a central ECU to control yaw torque, while the other is an individual ECU in charge of controlling each system and implementing cooperative control through communication between the ECUs. However, common VDM systems, managed by a central ECU, can fail when some faults arise such as when wrong sensor signals are received or following breakdown of the central ECU [3,4,5,6]. Therefore, it is necessary to design modern UCC strategies including fault-tolerant/fail-safe architectures and some level of redundancy as well as have effective coordination of each control modules. It is also needed to design new hardware architecture to improve the reliability as well as reduce the operating load for implementation of complicated UCC system.

This paper proposes multi-core architectures for implementation to increase the reliability and performance. In this paper, UCC system is separated to Supervisor, Main Controller, FDI/FTC logic by its function. Moreover, fault of sensor and brake actuator is diagnosed features for reliability of the control algorithm by analytical redundancy. Two types of multi-core architectures such as distributed processing and

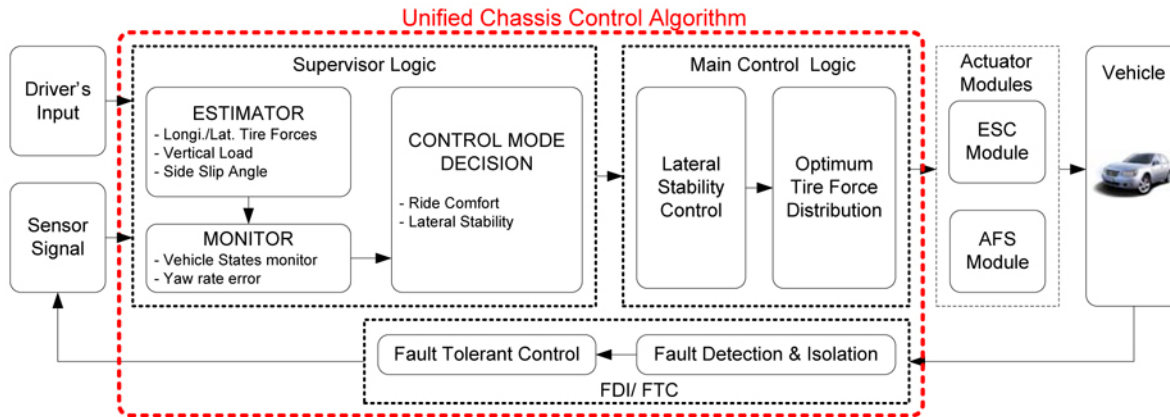


Figure 2.1. Scheme of the unified chassis control algorithm

triple voting are implemented to investigate the improvement of the performance and reliability. A vehicle simulator and brake HILS are used to evaluate the proposed multi-core architectures.

The second section of this paper describes the UCC algorithm implemented in this system. Next, the multi-core ECU implementation is presented in section 3. The HILS simulation results and comparison of the proposed three types of architectures are given in section 4. Finally, conclusions are made in section 5.

2. UNIFIED CHASSIS CONTROL ALGORITHM

The UCC algorithm used in this research consists of three structures which are supervisor, main controller and FDI/FTC as shown in figure 2.1. Going into more detail, the supervisor estimates some vehicle state variables to monitor the vehicle behavior, and then the yaw rate error is calculated to decide the control modes such as ride comfort, lateral stability [7]. The main controller generates the desired braking force and desired yaw moment for lateral stability control, respectively. FDI/FTC detects and recovers faults in the yaw rate sensor, the brake pressure sensor and the brake actuators at the individual wheels.

<figure 2.1 here>

2.1. SUPERVISOR LOGIC

The supervisor logic is comprised to estimator, monitor, and control mode decision. In the estimator part, the vehicle statuses are estimated to determine control mode and be used to Main Control Logic. Also, the longitudinal/lateral tire forces, tire-road friction, vertical load and side slip angle are estimated to use for optimum tire force distribution in main control logic. The estimator uses the measurable signals from the sensors equipped with the ESC and AFS modules. Many research results about side slip angle, longitudinal/lateral tire

forces, vertical load, and tire-road friction estimation have been published [8,9,10,11,12,13,14]. In this study, previously developed methods are adopted to estimate vehicle states.

In the monitor part, the yaw rate error is monitored whether vehicle lose the stability regarding to the lateral stability. The yaw rate error is defined as follows [13].

$$e_r = \gamma - \gamma_d$$

$$\gamma_d = \frac{1}{1 - \frac{m(l_f C_f - l_r C_r) v_x^2}{2 C_f C_r (l_f + l_r)^2}} \frac{v_x}{l_f + l_r} \delta_f$$
(1)

In equation (1), γ is the yaw rate measured by sensor and γ_d is desired yaw rate determined by using a 2-D bicycle model with a linear tire model as follows.[13]

Control mode decision system determines the control mode from the yaw rate error calculated by the monitor. In this study, control mode consists of the ride comfort mode and the lateral stability mode. Alternative of these two modes is selected by the yaw rate error threshold. If yaw rate error exceeds to its threshold value, the lateral stability control mode is activated. The lateral stability control is achieved by the yaw moment control to track the desired yaw rate.

2.2. MAIN CONTROL LOGIC

The main control logic operates the lateral stability control. In the lateral stability control mode, the control input is only the control yaw moment which is determined to track the desired yaw rate which is generated on the basis of the driver's steering input. From the desired yaw moment, additional steering angle and braking pressures at the individual wheels are calculated based on the optimum distribution method as inputs of the ESC and AFS. In a conventional ESC, the

desired yaw moment is generated by differential brake which causes longitudinal deceleration as well as decreasing the comfort for the driver. From previous research [13], an optimized coordination of the AFS and ESC has shown that the proper usage of braking leads to increase the performance of the control system and minimize the deceleration by the braking control input.

The desired yaw rate is expressed as a function of the vehicle longitudinal velocity and driver's steering input in [equation \(1\)](#), the prior section 2.1.2. The control yaw moment is determined from [equation \(1\)](#) by using the 2-D bicycle model and a sliding mode control method as follows:

$$M_z = -I_z \left(\frac{2(-l_f C_f + l_r C_r)}{I_z} \beta - \frac{2(l_f^2 C_f + l_r^2 C_r)}{I_z v_x} \gamma + \frac{2l_f C_f}{I_z} \delta_f \right) - K_1 \text{sat} \left(\frac{\gamma - \gamma_d}{\Phi_1} \right) \quad (2)$$

where,

$$K_1 = I_z \left\{ \frac{F_{yf}}{I_z} \left| -l_f \beta - l_f^2 \gamma + l_f \delta_f \right| + \frac{F_{yr}}{I_z} \left| l_r \beta - l_r^2 \gamma \right| + |\dot{\gamma}_d| + \eta_1 \right\}$$

η_1 is a positive constant, and Φ_1 is a control boundary.

In a conventional ESC, the desired yaw moment is generated by differential brake which causes longitudinal deceleration as well as decreasing the comfort for the driver. Also, the frequent additional braking control inputs could lead to excessive wear of the tires and brakes. From previous research [13], an optimized coordination of the AFS and ESC has shown that the proper usage of braking leads to increase the performance of the control system. An optimal coordination of the longitudinal and lateral tire forces $(\Delta F_x, \Delta F_y)$ are determined by the Karuch-Kuhn-Tucker (KKT) condition.

2.3. FDI/FTC LOGIC

As research continues, according to the vehicle system becomes more sophisticated and integrated, the failing probability of sensors and actuators has increased significantly. The reliability of sensors and actuators is important factor for the successfully integrated system. Usually, sensor and actuator faults are result from short-cuts or cut-offs in their connectors and wirings resulting in changes in the gain of the bias [17]. These actuator faults and sensor faults may induce the malfunctioning of the UCC system, and lead to dangerous situations that threaten the safety of the driver and the passengers of vehicles. A fault tolerant system can improve the UCC algorithm reliability by securing robustness against various faults and malfunctions in the sensors and actuators. In this study, the FDI/ FTC logic is employed to detect and compensate the failures due to the brake sensor/actuator and the yaw rate sensor. The schematic diagram of the proposed FDI/ FTC system is given [figure 2.2](#).

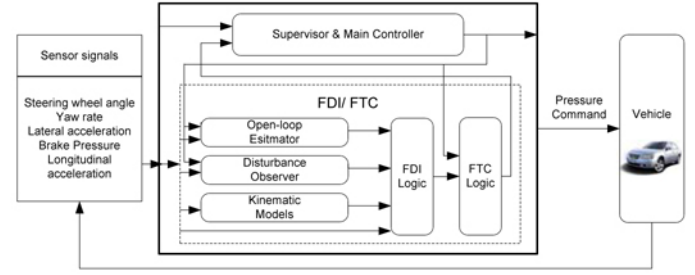


Figure 2.2. Proposed FDI/FTC scheme

2.3.1. Fault detection & isolation

The FDI system is operated the basic operation sequence can be described as the following. Firstly, the vehicle states for the fault detection are monitored with the presented open-loop estimator, the disturbance observer and kinematic model. When a sensor or an actuator failure occurs, the fault is detected by evaluation of the residual signals generated by comparing with dynamic thresholds. The residuals are calculated using an open-loop estimator, a disturbance observer and kinematic models. [18].

2.3.2. Fault tolerant controller

The yaw rate sensor, lateral acceleration sensor, steering wheel angle sensor, brake pressure sensor and brake actuators are important in ensuring an accurate UCC system. In this study, kinematic based fault tolerant logic is implemented in the event that the yaw rate sensor and brake pressure actuator failure. For example, in the case of the yaw rate sensor failing, the yaw rate sensor signal, which is fed back to the control system, should be replaced by the estimated value, γ_{est} , by using the lateral acceleration sensor signal and vehicle longitudinal velocity in order to secure the vehicle as follows:

$$\gamma_{est} = \frac{a_y}{v_x} \quad (3)$$

When the one of the brake actuator is failed, the brake pressures should be redistributed by the remaining actuators, which are available. The total brake force, $\sum F_x$, and yaw moment, $\sum M$, have a relationship in the normal situations as follows:

$$\sum F_x = \frac{K_{bf}}{r_{wf}} (P_1 + P_2) + \frac{K_{br}}{r_{wr}} (P_3 + P_4) \quad (4)$$