Vehicle Handling Improvement with Steer-by-Wire System Using Hardware in the Loop Method

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ABSTRACT
In this paper, a control algorithm for improving vehicle handling has been proposed by applying correction angle to the steered wheel, based on the optimal and adaptive theory using Simulink MATLAB software. A 4DOF model with nonlinear tire and SBW subsystem is presented using hardware in the loop method. Since some space variables cannot be measured, an estimator is used to extract the measurable variables from the simulated model and convert them to the required variables of the controller. These variables are transmitted to the controller and then it adopts itself with new conditions and applies the best modification on the steering. The results reveal that the proposed controller can significantly improve vehicle handling during severe maneuvers.

Keywords: Handling; vehicle; steer-by-wire; controller; hardware in the loop method.

1. Introduction

The automobile industry is currently working on new Drive-By-Wire (DBW) systems in which mechanical and hydraulic subsystems, such as steering, braking and suspension, are being replaced by electronic actuators, controllers, and sensors. The benefits of applying electronic technology, like DBW systems, are clear: improved overall performance and driving convenience reduced power consumption and significantly enhanced passenger safety. Steer-by-wire systems are a relatively new development compared to the traditional mechanical, hydraulic, or electric steering systems that are currently used for motor vehicles.

In Steer-By-Wire (SBW) systems, a part of the DBW, the conventional mechanical interface between the steering wheel and the front wheels is replaced with electronic actuators. The elimination of parts, such as the steering column, gear box and hydraulic pump, provides advantages including saving energy, decreasing noise and vibration, reducing weight and removing environmentally hazardous hydraulic fluids. Moreover, in front-end collisions, the danger of a driver being crushed is reduced because there is no steering column [1-2].

There are several main steering function requirements for a steer-by-wire system:

(1) Directional control and wheel synchronization: Directional control is the basic requirement for vehicle steering systems, including steer-by-wire systems. It is required that road wheels follow the driver's input command from the steering wheel and the possible input commands from the supervisory vehicle control systems according to vehicle dynamics requirements. The road wheels should maintain synchronization with the steering wheels in real time without bias, offset, or time delay.

(2) Adjustable variable steering feel: The steering feel provides information on the force (or torque) at the road wheel tire-road surface contact and varies depending on road conditions. This force/torque information should be fed backed to the steering wheel to produce steering wheel torque that can be felt by the vehicle driver. The vehicle driver relies on the steering feel to sense the force of road wheel tire-road surface contact and maintain control of the vehicle. Thus, steering feel has been becoming one of most important vehicle attributes to maintain vehicle directional control and stability. In a steer-by-wire system, it is required to generate

not only a familiar steering feel to the vehicle driver just as in the conventional steering wheel systems with mechanical connection, but also adjustable variable artificial steering feels.

(3) Adjustable steering wheel return capability: The steering wheel should return automatically to the wheel center or a predefined angle if the hands of vehicle driver leave the steering wheel. The return rates of the steering wheel can be adjusted based on the vehicle speed.

(4) Variable steering ratio: The steering ratio is a ratio between steering wheel angle and road wheel angle. It is typically fixed around 16 to one in conventional steering wheel systems. A variable ratio permits a significant improvement in handling performance and vehicle dynamics. It can be a function of vehicle speed, steering wheel angle, and other variables [3].

Undoubtedly, the greatest benefit of SBW is its active steering capability, that is, the ability to change the driver’s steering input to improve maneuverability or stability. Therefore, the research institutes and automotive industry pay considerable attention to the potential benefits of SBW systems, particularly for improving vehicle handling behavior. Over the last two decades, a number of studies have been carried out on control of vehicle handling and stability using SBW architecture. Yih [4] addressed some of the issues associated with control of a steer-by-wire system. A general steering control strategy was developed to emphasize the advantages of feed forward. The controller was implemented on a test vehicle that was converted to steer-by-wire. Kazemi and Janbakhsh [1] proposed a nonlinear adaptive sliding mode control that aims to improve vehicle handling through a Steer-By-Wire system. Their results confirmed that the proposed adaptive robust controller not only improves vehicle handling performance but also reduces the chattering problem in the presence of uncertainties in tire cornering stiffness. Qiu et al. [5] built a simulation model of SBW, including steering motor model, steering executive system model, vehicle model and Fiala tire model. Based on the Linear Active Disturbance Rejection Control (LADRC) technique, a kind of control algorithm on steer angle of vehicle SBW was designed. Marumo et al. [6] discussed the control effects of the SBW system for motorcycles on the lane-keeping performance by examining computer simulation with a rider-vehicle system which consisted of a simplified vehicle model, a rider control model and the controller of the SBW system. Tavoosi et al. [7] developed a 4DOF simplified model for steering system using vehicle parameters for standard maneuvers in dry and wet road conditions. They used the hardware in the loop method to prove the controller ability in realistic conditions. They showed the effectiveness of NAOC on vehicle handling and reveal that the proposed controller can significantly improve vehicle handling during severe maneuvers.

In this paper, a 4DOF model with nonlinear tire and SBW subsystem is presented using hardware in the loop method. Since some space variables cannot be measured, an estimator is used to extract the measurable variables from the simulated model and convert them to the required variables of the controller. These variables are transmitted to the controller and then it adopts itself with new conditions and applies the best modification on the steering. The Simulink MATLAB software is used for vehicle modeling.

2. Vehicle dynamic modeling

The Lagrangian method was used to extract the vehicle lateral motion equations. The proposed model is a 4DOF model including roll angle, longitudinal speed, lateral speed, roll rate. According to Fig. 1, Eq. (1) was obtained as follows [8-10]:

$$
\begin{aligned}
& m(\dot{u} - rv - h'j\dot{r} - 2h'r\dot{j}) = \\
& 2F_{xf} + 2F_{xr} - 2F_{yf}d \\
& m(\dot{v} + ru + h'\ddot{j} - h'r^{2} j) = \\
& 2F_{yf} + 2F_{yr} + 2F_{xf}d \\
& I_{z}\dot{r} + (I_{z}q_{r} - I_{xz})\ddot{j} - mh'(u - rv)j = \\
& 2aF_{yf} - 2bF_{yr} + 2aF_{xf}d + M_{Z} \\
& (I_{x} + mh'^{2})\ddot{j} + mh'(\dot{v} + ru) + (I_{z}q_{r} - I_{xz})\dot{r} - \\
& (mh'^{2} + I_{y} - I_{z})r^{2} j + (c_{jf} + c_{jr})\dot{j} \\
& +(k_{if} + k_{ir} - mgh')j = 0
\end{aligned}
\tag{1}
$$