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Direct Current Measurement Based Steer-By-Wire Systems for Realistic Driving Feeling

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Abstract - **In this paper, a method to reproduce realistic driving feeling and improve the returnability of steer-by-wire systems (SBW) is proposed by measuring the roadwheel motor's current directly. The key contribution presented here is a novel method to recreate the driving feeling in term of force feedback with simple and cheap current sensors. A current sensor is used to fully measure the steering torque on the rack of steering mechanism. This measured steering torque therefore, includes the overall effects of road conditions, aligning moments, tire properties and so on. Beside that, a free control scheme is proposed to improve returnability as well as the handwheel stability in a free motion. Moreover, during this research, the significant frequency effect of handwheel motions was found. This effect could be useful and valuable for improving steer-by-wire development based on torque-map based method. This method is investigated with simulation results using the control design and simulation module in LabVIEW programming language. The simulated results show that this method offers a cheaper and simpler solution for the development of steer-by-wire systems. In addition, stability and returnability of handwheel in steer-by-wire systems could be improved.**

I. INTRODUCTION

Steer-by-wire is the innovative version of an automotive steering system shown in Fig. 1. In the SBW system, a driving signal given by a driver is transmitted to the road wheels through electrical wires while this signal is transmitted through mechanical and, or hydraulic linkages in conventional steering systems.

Thanks to the absence of the mechanical connection between the handwheel (HW) and the roadwheel (RW), SBW systems offer several advantages such as lager space in the cabin, freedom in car interior design, no oil leaking, and less injury in case of car accidents. However, there are also numbers of disadvantages due to the lack of mechanical connection. For example, the lack of realistic driving feelings, which is the driving feelings for the driver as in conventional steering systems. SBW systems can be out of order because of electrical faults. In addition, the difficulty of the free control of the handwheel, which is the HW behavior, after the driver's hands release at certain steered position of the HW. One of the most challenging issues on SBW development is how to give drivers the realistic feelings or realistic force feedback which is the same as conventional hydraulic steering systems. The force feedback for SBW systems has been studied by many researchers, [1], [2], [4], [5], [9]. In 1966, E.R Hoffmann [1] and P.N. Jouber studied on the effect of changes in some vehicle handling variables on driver steering performance.

In 1995, Andrew Liu and Stacey Chang [2] described three experiments conducted in a driving simulator that explore how force feedback information may be used by the driver and to see how steering torque information is affected by the variance of the steering movements. Recently, disturbance observer-based approach is implemented by Yih, P. and Gerdes, J.C. [13], and Shoji Asai, 2004 [5], etc. For this method, the realistic feelings could be obtained from the dynamic model using an observer. However, the exact models of steering system and vehicle as well as powerful microcontrollers are essential here.

Some papers [15], [16],have proposed a torque map-based method, in which, the force feedback can be obtained with a force control loop. A torque map is a reference input of the force feedback control. This torque map is the combination of several signals such as vehicle velocity, HW angle, etc. Attaching torque sensors to the rack of the steering system is proposed by PI [16]. However, prices and heavy working conditions of torque sensors in steering system are the biggest disadvantages for those methods.

In this paper, we propose a novel method to make the realistic feelings in the SBW system the same as the driving feelings in hydraulic power steering systems. This method is inexpensive, easy to develop, and less complexity.

II. STEER-BY-WIRE SYSTEM

A. Conventional mechanically connected steering and SBW

In conventional mechanically connected steering systems, such as hydraulic power assisted steering systems, Fig. 1a; the HW rotation given by a driver is transmitted via a intermediate shaft. The column is connected to the rack and roadwheels. Therefore, the roadwheel angle is proportional to the HW rotation. An amplified hydraulic pump is used to reduce the driver's steering efforts.

In SBW, Fig. 1b, the intermediate shaft, and the hydraulic pump are removed. And several position sensors and actuators are attached to the HW and RW. The encoder at HW is to observe HW motion. The HW motion, then converted into electrical signals and wired to an electronic control unit (ECU). The ECU controls an RW actuator for rotating the RW part in the same manner of the HW behaviors. The second encoder at

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RW is for implementation of closed-loop position control. Because of the absence of physical connection, a DC motor at the HW is needed to recreate driving feelings.

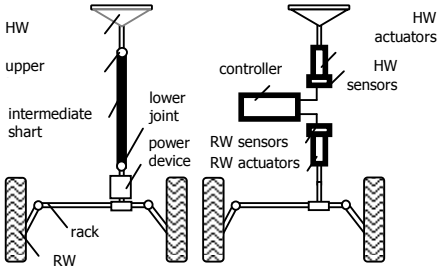

Fig. 1 Conversion from conventional steering system to SBW

To make SBW features close to conventional steering systems, several requirements have to be met. Position tracking, which is the fundamental function of a normal steering system. This ensures the RW exactly copy the HW motions for accurate steering control. Realistic force feedback, which makes steer-by-wire system to has the same driving feelings as in a hydraulic steering system. From previous researches [3], [5], [8], [10], the driving feeling is one of the most difficult issues for steer-by-wire development. Free control refers to the response of the HW after a sudden release from the certain position of the HW. In this case, a quick return to center with minimal overshoot is desired [6].

B. Modeling of Steer-By-Wire System

Basically, a SBW system can be considered as a two-port network whose schematic arrangement is shown in Fig. 2. The driver gives position to the HW. Then, this motion is tracked by the RW. In turn, the interaction of the road surface and tires produces an interacting torque. With mechanical dynamics, this torque causes the driving feeling for drivers.

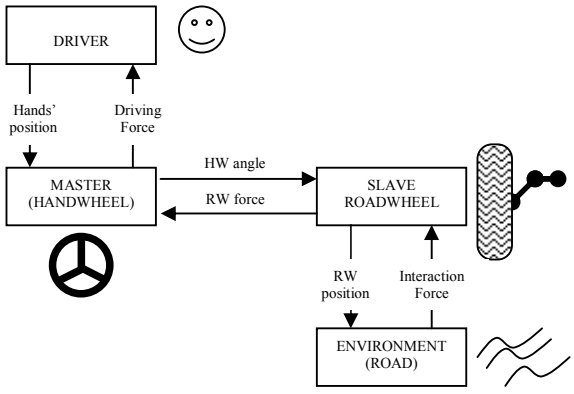

Fig. 2 SBW is considered as a two-port network

The model of SBW system simplified as the Fig. 2 consists of two parts, handwheel and roadwheel. In the HW part, θ_{hw} angle is the HW input given by the driver, τ_h is human torque applied on the HW. The equation for SBW modeling is presented in equation (1). τ_{RWact} is HW actuator torque, τ_{HWfr} is friction of the HW part. For other explanation of notations in this equation, please see [TABLE 1].

$$J_{hw}\ddot{\theta}_{hw}+b_{hw}\dot{\theta}_{hw}+\tau_{HWfr}=\tau_h+\tau_{HWact} \quad (1)$$

In the RW part, θ_{rw} is the RW actuator's angle. RW is actuated by motor torque τ_{RWact}. If there is a contact between tires and the road surface, aligning torque τ_a will occur because the existence of caster and kingpin angles in a steering mechanical structure. τ_{RWfr} is friction of the RW part. Finally, with tire-to-ground contact, the model of RW part of the SBW system can be expressed as equation (2).

$$J_r\ddot{\theta}_{rw}+b_r\dot{\theta}_{rw}+\tau_{RWfr}+\tau_a=\tau_{RWact} \quad (2)$$

The location of torques, angles, and moments are illustrated in Fig. 3.

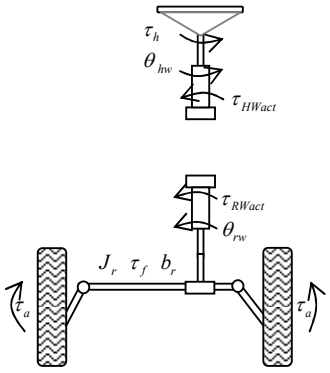

Fig. 3 Modeling of a SBW system

III. CURRENT APPROACH

In this section, we focus on the force feedback implementation for the SBW systems. Normally, the force feedback known as driving feelings is from the RW part. This includes moment of inertia and damping; align moment, joints' friction. The feedback force is also affected by tire properties, road condition, vehicle velocity, and so on.

In hydraulic steering systems, this force is transmitted to a driver after power modification of based on a hydraulic pump for convenient of HW control. However, in SBW system, this force must be artificially recreated by the HW actuator. Therefore, a realistic force feedback including all the mentioned effects becomes an essential factor in SBW.

A. *Model-based approach*

Normally, to recreate the force feedback, the moment of inertia and damping, and friction can be calculated as soon as their constants are identified. The most complex and difficult issue is how to calculate align moment.

To solve this, several solutions are introduced. Those include model-based approach [8], [13], [18], torque sensor-based method [9], [15], torque-map method [3], [15].

Recently, J. Christian Gerdes and al, [13] have developed HW force feedback based on a disturbance observer in which