

Bilateral Control Method of Torque Drive/Angle Feedback Used for Steer-by-Wire System

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ABSTRACT

Steer-by-Wire system is capable of improving the performance of vehicle handling and stability, and assisting driving. It becomes a key technique to control front wheel angle and simulate the steering resistance delivered to the driver because of removing mechanical linkages between the steering wheel and the front wheels. This paper proposes a bilateral control method of steering wheel torque drive/pinion angle feedback, which is disaccustomed of controlling steering wheel block and steering actuator as master-slave plants. The pinion angle, steering wheel angle and its torque signals are used in the control logic without estimating or measuring the tire/road force. Simulations and vehicle experiments proceeded with this proposed method and the results confirmed that it achieves the bilateral control of the position and torque between the two plants. Meanwhile, the characteristics of the steering and returning dynamics obtained are very similar to conventional mechanical steering systems.

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INTRODUCTION

Steer-by-Wire (SBW) system, in which the mechanical linkages between the steering wheel (SW) and the front wheels are removed, has many advantages. It enables the steering system to use variable angle and torque transmission ratio to reduce the driver's angle and power input at low speed. It brings a fundamental resolution to the conflict between handiness and sensitivity in the conventional steering system, also enhances the road feeling at high speed. In addition, SBW system can coordinate with the other chassis electric control systems to improve the vehicle's stability and maneuverability. The arrangement and assembly of the system would be more convenient because the SW block and steering executive block are mechanically separated.

All of the SBW control strategies regard the SW block and the steering executive block as the master-slave system: [1] The road wheel steers passively according to the angle determined by the SW and vehicle states; The steering resistance delivered to the driver is simulated by the motor according to the SW angle and vehicle speed, or the estimated or measured value of the rotational resistance between the road and the wheel. [2,3] To get the road information for the driver, it requires that the SBW system should estimate or measure the resistance accurately in real-time. The road/wheel force can be obtained by an observer or

a torque sensor. However, there is a multitude of work to establish an observer and to identify the parameters of steering executive block; Also, it is difficult to attach a torque sensor whose bandwidth is narrow. [4]

Considering the SBW structure, a bilateral control method of torque drive/angle feedback is proposed. It depends on the signals of the SW torque and angle and the pinion angle as well as the currents of the force simulation motor and the steering executive motor. Without the resistance signal, the steering force simulation can also be implemented through the position feedback control and the characteristic design of the system torque ratio. Therefore, the states of the SBW system are completely determined by the input torque from the driver and the interaction force between the front wheels and the road, which is consistent to the dynamics of the mechanical steering system.

SBW SYSTEM AND VEHICLE MODEL

SBW System Model

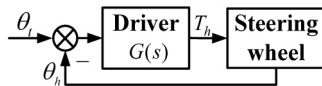
The SBW system is comprised of two blocks, the SW block and the steering executive block. The former can be refitted by an EPS column with a torque sensor and an assistant motor for simulating steering resisting torque. A

Table 1. Parameters of the SBW system and the vehicle model.

Stiffness of Torsion Bar k_c	200Nm/rad
Reduction Ratio r_g	18
Moment of Inertia of SW J_h	0.005kg/m ²
Moment of Inertia of Motor J_m	0.0001kg/m ²
Damping Coefficient of SW B_h	0.2Nms/rad
Damping Coefficient of Motor B_m	0.007Nms/rad
Back EMF Constant of Motor k	0.053Vs/rad
Inductance of Motor L	0.001H
Resistance of Motor R	0.18 Ω
Radius of Pinion r_p	0.0085m
Length of Knuckle Arm r_l	0.14m
Friction at Pinion f_p	0.48Nm
Moment of Inertia at Pinion J_p	0.0339kg/m ²
Damping Coefficient at Pinion B_p	2.5848Nms/rad
Cornering Stiffness of Front axle C_{af}	86000N/rad
Cornering Stiffness of Rear axle C_{ar}	124000N/rad
Pneumatic Trail of Tire t_p	0.0381m
Mechanical Trail of Tire t_m	0.04572m
a	1.016m
b	1.436m
Vehicle Mass m	1359.8kg
Vehicle Yaw Moment of Inertia I_z	1992.5kg

Driver Control Model

Most of vehicle test procedures require a SW angle input, while the steering torque is taken as an input in a SBW system. To solve the problem, a PID controller is considered as the driver as shown in Figure 3, the error between the target SW angle θ_t and the real angle θ_h is controlled by the torque input T_h of the driver.

**Figure 3. Structure of the driver control model.**

Where, $G(s) = k_p + k_i \frac{1}{s} + k_d s$, the parameter tuning result is $k_p=60$, $k_i=300$, $k_d=1$.

THE BILATERAL CONTROL METHOD OF SBW SYSTEM

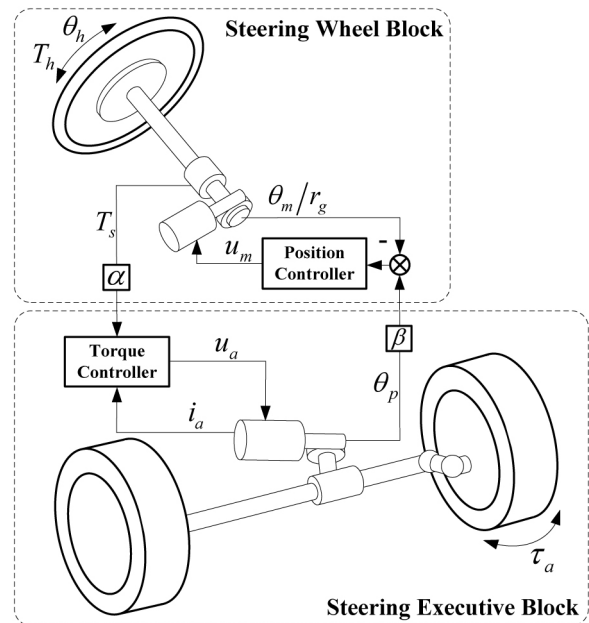
Control Requirements of SBW System

As there are no mechanical linkages between the SW and the steering pinion, the SBW system is actually a bilateral teleoperation system with telepresence, which means that a human is able to interact with a distant environment as if he or she were there [4]. The driver rotates the SW to turn the

SW. At the same time, the driver could sense the adhesion state of the road, the lateral acceleration of the vehicle and other information through the SW's force feedback. And this requires that the control strategy can replace the function of the original steering shaft, coordinate the control of the two blocks, between which the torque and the angle should be coupled.

Control Strategy

Considering the limitation of the actuators' hardware and the functional requirements of the steering system, this paper proposes a bilateral control method of torque drive/angle feedback. Figure 4 is the control diagram. The control structure regards the steering executive block as 'master' and the SW block as 'slave'. θ_m/r_g is controlled by the position controller of the SW to realize the angle coupling, according to θ_p and the angle ratio β from the SW to the pinion; i_p is controlled by the torque controller of the steering motor to realize the torque coupling, according to T_s and torque ratio $1/\alpha$ from the SW to the pinion. In order to prove the proposed bilateral control strategy conveniently, we assume that $\beta=1$. And the determination of α is similar to the basic assistance characteristics of EPS.

**Figure 4. The bilateral control diagram.**

Using this method, the road wheel angle is fed back to the driver and the steering motor is torque controlled according to the torsion bar torque. Here are the benefits: (a) When SBW system initializes, the SW would be adjusted in corresponding to the pinion angle without rotating the road wheel; (b) When the vehicle is returning to center, the executive block's states mostly depends on the alignment torque, which accords with the returnability performance of the mechanical steering system; (c) It has remarkable flexibility that the vehicle performance of handiness at a low