

A Study of Steering System Model for Steering Feel's Improvement of Steer-by-Wire System

¹Ilhwan, Kim*, ¹Jonghyun, Lee, ²Seung-Jin, Heo

¹Graduate School of Automotive Engineering, Kookmin University, South Korea, ²School of Mechanical & Automotive Engineering, Kookmin University, South Korea

KEYWORDS – Steer-by-Wire system, Reactive torque generation, Steering system model, HiS

ABSTRACT - Steer-By-Wire(SBW) system is the one of the advanced technologies that will be applied to steering system for the next generation's vehicles. It removes mechanical linkages between steering wheel and front wheels. As a result, SBW enhances controllability of vehicle dynamic characteristic and safety of car crash, and simplifies vehicle design process. The main purpose of this study is to focus on steering system model for steering feel improvement. It is very important to be developed for a driver to adjust the steering feel, as if hydraulic steering system conveys. In this study, the steering system model is designed by Matlab/Simulink and LabVIEW, and verified by real-time simulation using Carsim RT and LabVIEW RT.

INTRODUCTION

Steer-By-Wire(SBW) system is the one of the advanced technologies that will be applied to steering system for the next generation's vehicles. With a conventional steering system, there is a mechanical linkage between the steering wheel and front-wheels. Therefore, it has many weak points - limitation on design variable of suspension system, a difficult engine room design, lower efficiency because of using hydraulic pump. And when vehicle got shocked, a steering column which consists of mechanical structure gives drivers serious injury. Recently the SBW system has been developed at a good pace, because those are become.

Because the SBW system can make of system components except for the intermediate steering shaft, which is cut in half with the upper end completely removed, it will be reduced vehicle's weight, engine power loss. As a result, fuel efficiency, design variable, driver's convenience and crash safety are improved. However, drivers can feel unfamiliar the steering feel and reduce driving stability in the SBW system.^{(1),(2)}

In this study, the steering system model for reactive torque generation is designed by Matlab/Simulink and LabVIEW, and verified by real-time simulation using Carsim RT and LabVIEW RT.

14 DOF FULL VEHICLE MODEL

Steering reactive torque felt by drivers is sum of factors which are road's friction and tire's force of longitudinal, lateral and vertical. This study develops full vehicle model used Matlab/SIMULINK for exact reactive torque generation.

14DOF full vehicle model consists of horizontal 3DOF, vertical 7DOF, and tire 4DOF model. Individual motion of each model's input-output relation is following figure 1.⁽³⁾

Tire model received steering input, both vehicle velocity and yaw angular velocity, and vertical force from driver, horizontal, and vertical model. Based on input data, longitudinal and lateral force are sent to the output by using lookup table.

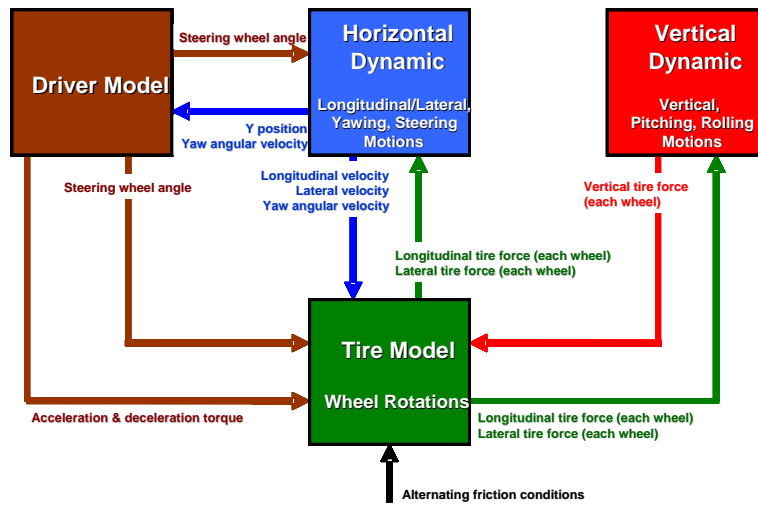


Figure. 1: Modular architecture of full vehicle model

Verification of model

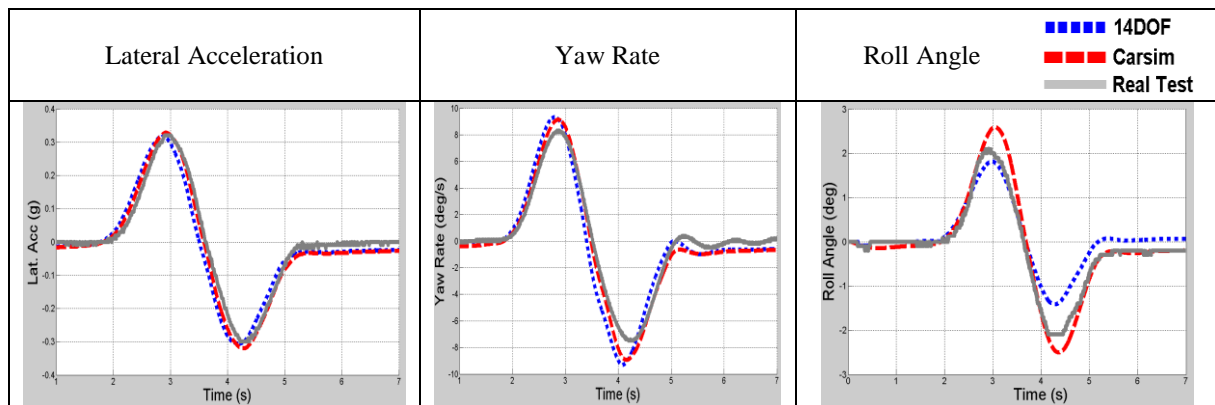


Figure. 2: Result of single lane change(14 dof model vs. Carsim vs. test)

Figure. 2 shows that result of single lane change simulation of 14 DOF model, Carsim and practical data in the same condition. 14 DOF model shows that accuracy of lateral acceleration and yaw rate in single lane change. But, this model has difference of 17% error in roll angle. Generally, 14DOF model show that accuracy of 85~98% according to, kind of result. It represents alike result using Carsim. But, little error is considered ignoring the difference of suspension's kinematics and compliance effect. Also, road condition not reflected on model is one of the errors.

STEERING SYSTEM MODEL

Driver torque or hand-wheel torque is required to steer front wheel angle of their input value. The front wheel is steered by this torque which is transmitted by tie-rod through several links. Driver torque is resisted by reactive torque consists of tire self aligning moment, jacking force and road friction force. Considering the above explanation, steering system is described by the following differential equation.

$$I_{hdl}\ddot{\theta} + D_{hdl}\dot{\theta} + T_{align} + T_f = T_{hdl}$$

Where I_{hdl} and D_{hdl} are the moment of inertia and damping of the steering system at the front wheels.

Reactive Torque Generation

In this study, two factors – tire self aligning moment and road friction force – considered for reactive torque generation.

Firstly, the tire self aligning torque, T_{align} , is a function of the steering geometry, particularly caster angle, and the manner in which the tire deforms to generate lateral force, F_y . In Figure. 3, F_y acts on the centroid of tire force, t_p is the pneumatic trail, the distance from the center of tire to the application of lateral force, t_m is the mechanical trail, the distance between the tire center and the steering axis. Therefore T_{align} which is occurred by tire deformed by the above explanation has the degressive characteristic when the tire slip angle rises, which shows as Figure. 4.

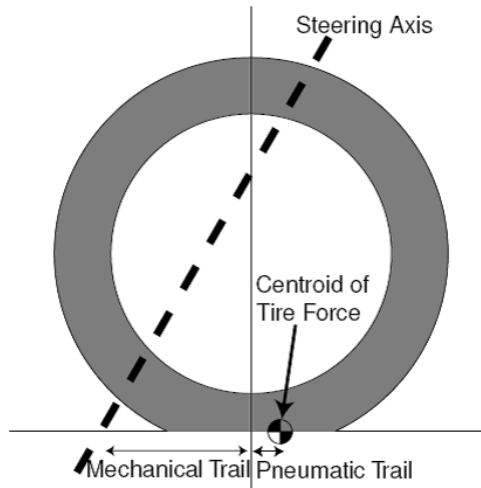


Figure. 3: Steering geometry causing aligning moment

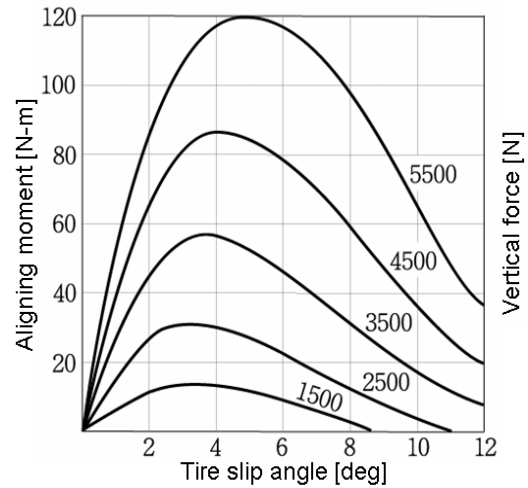


Figure. 4: Characteristic of aligning moment

So the following function shows simply the tire self aligning moment, if vehicle's velocity is constant and tire lateral force isn't considered.

$$T_{align} = (t_m + t_p)F_{yf}$$

$$= (t_m + t_p)C_{cf} \left(\delta - \frac{a\gamma}{V_x} - \beta \right)$$

The pneumatic trail can be calculated by function of road friction coefficient, cornering stiffness, tire slip angle included initial value, which shows follows. And the mechanical trail is constant because the design factor is assumed.

$$t_p = t_{t0} - \text{sign}(\alpha_f) \frac{t_{t0} C_{cf}}{3\mu F_z} \tan(\alpha_f)$$

The others is the friction force. It is function of road friction coefficient, vertical force, pneumatic trail and steering wheel angle rate as follows.^{(4),(5)}

$$T_f = \mu N t_p \text{sign}(\dot{\delta}_f)$$

Fig. 5 shows the tire self aligning moment of 14-dof full vehicle mode and Carsim test result. In fig. 5, it can be appreciated that both tire self aligning moments are approximately calculated.

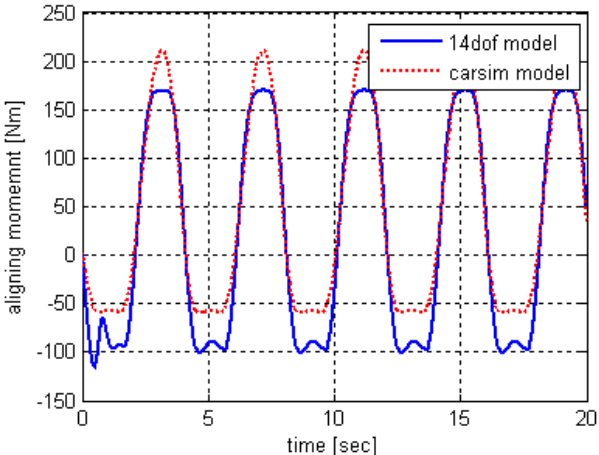


Figure. 5: Aligning moment estimation

STEERING WHEEL SIMULATOR

Composition of Hardware

The steering wheel simulator consists of steering wheel, potentiometer, coupling, torque sensor, coupling, reducer and motor in sequence, as show Figure. 6. The potentiometer of contactless type and multi-turn measurement is used for measuring steering angle. The torque sensor of rotational contactless type is used for directly measuring drivers’ steering wheel torque at the steering column. The coupling of flexible type is used for preventing each component from breakdown by unbalance. Finally, reducer and motor, which transmit calculated reactive torque to steering wheel, play an important role familiar whit conventional steering feel in SBW system. And each component’s safety factor is designed 1.5 because of considering emergency situation.

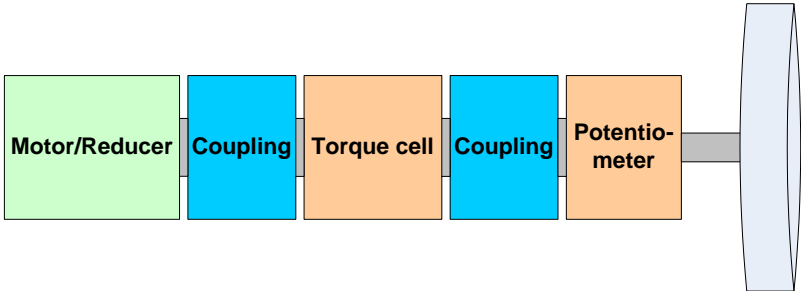


Figure. 6: Steering wheel simulator block diagram

Composition of System controller

Servo amp and electric circuit is needed for driving motor. In addition, digital signal of DI/O(Digital In/Output) board is used to input several parameters for servo amp control. Figure. 7 shows simple block diagram of system controller. In this study, NI PXI system is used for real-time processor. Therefore, data can be acquired and system can be controlled in real-time.

Fig. 9 shows whole control flow of the steering wheel simulator. Firstly, drivers' steering wheel angle and torque about vehicle driving state are measured. And then the reactive torque is determined by steering model substituted for steering wheel angle rate, acceleration. It generated by motor's torque control is transmitted to steering wheel.

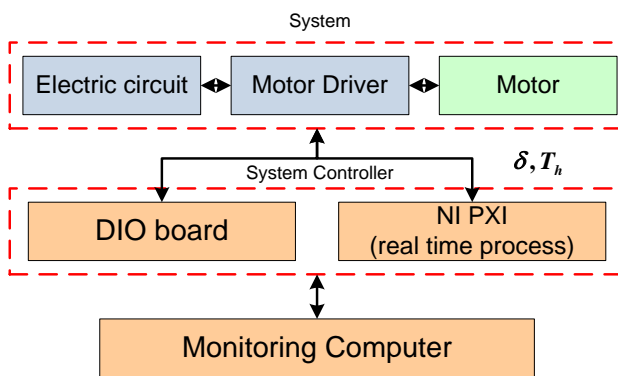


Figure. 7: System controller flowchart

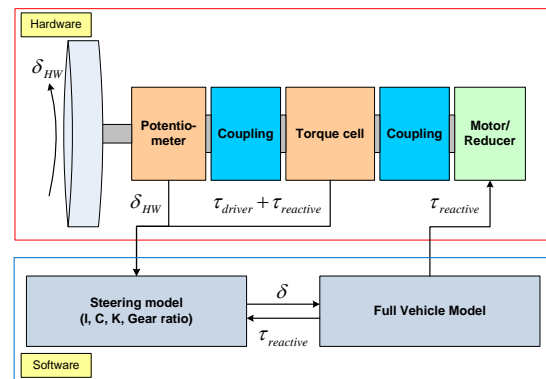


Figure. 8: Signal flow of steering wheel simulator

SIMULATION

For verification of the steering wheel simulator, test result is compared with simulation result. Vehicle driving condition is single lane change when vehicle velocity is 80kph.

Figure. 9 shows steering input used at test. Steering wheel angle is 50 degrees. In Figure. 10, the steering wheel simulator's result is compared with vehicle test's result. Both results are represented similar tendency. However, various simulations is needed because of system's accurate verification and tuning control logic for improving steering feel.

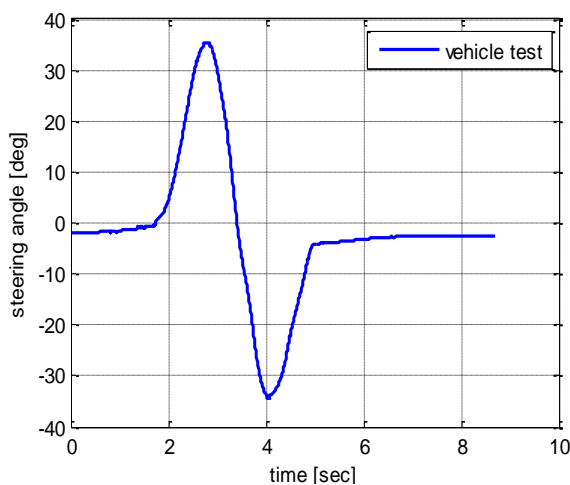


Figure. 9: Steering input (Single lane change)

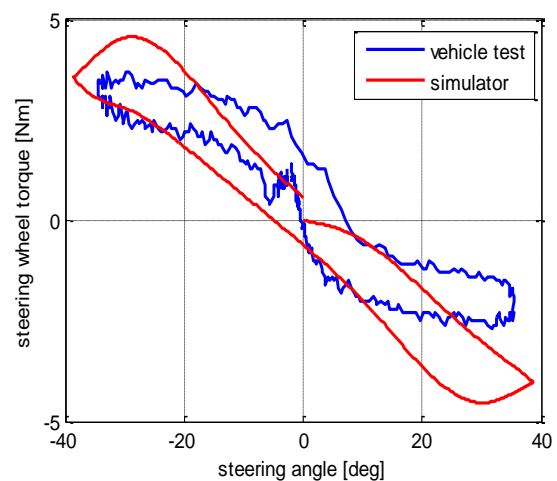


Figure. 10: Steering angle vs. steering wheel torque

CONCLUSION

The steering wheel simulator including a 14 DOF full vehicle model was developed in order to improve the technique of Steer-by-Wire system evaluation in a laboratory.

The reactive torque that drivers feel is one of the most important parts in SBW system. It can be simulated by the calculation of self-aligning moment and the other effects, which is derived from the tire characteristics of 14 DOF full vehicle model.

In this HIL simulator, estimated reactive torque is transfer to hand wheel force using an AC servo motor control. Simulation results in several cases are compared with actual vehicle testing and we can obtain comparatively accurate results. Drivers can feel the reaction torque, which includes mechanical characteristic and electrical characteristics, around the center position of the steering wheel in this steering wheel simulator.

In the future, technical issues identified in this study will be improved. For example, take reliability through on-center-handling test.

REFERENCES

- (1) S. C. Chang, "Study of Parameters Sensitivity for Steer-by-wire System", AVEC, 2006
- (2) Nakano, S., "Steering Control Strategies for the Steer-by-Wire System", Trans. Of JSAE, Vol. 31, NO. 2, pp. 61-67, 2000
- (3) Kihong Park, Seung-Jin Heo, "Development of White-box Full Vehicle Model Based on the Lumped parameter Model", KSAE, Vol. 2, pp.919-924, 2007
- (4) Yung-Hsiang, "A Method to Estimate the Friction Coefficient and Tire Slip Angle Using Steering Torque", IMECE, 2006
- (5) Paul Yih, "Steer-by-Wire for Vehicle State Estimation and Control", AVEC, 2004