

Development of Hardware-In-the-Loop Simulation System for Steering Evaluation Using Multibody Kinematic Analysis

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ABSTRACT

The adoption of the electronic controlled steering systems with new technologies has been extended in recent years. They have interactions with other complex vehicle subsystems and it is a hard task for the vehicle developer to find the best solution from huge number of the combination of parameter settings with track tests.

In order to improve the efficiency of the steering system development, the authors had developed a steering bench test method for steering system using a Hardware-In-the-Loop Simulation (HILS). In the steering HILS system, vehicle dynamics simulation and the tie rod axial force calculation are required at the same time in the real-time simulation environment. The accuracy of the tie rod axial force calculation is one of the key factors to reproduce the vehicle driving condition. But the calculation cannot be realized by a commercial software for the vehicle dynamics simulation. A multibody kinematics model of strut suspension was developed for the tie rod axial force calculation.

In this study, a new kinematics model of a double wishbone suspension system was developed for the tie rod axial force calculation. The evaluation of developed kinematics model was carried out by comparing the results of a kinematic analysis and the tie rod axial force calculation to those of ADAMS. Then the evaluation of the reproducibility of the vehicle driving condition in the steering HILS system was carried out by comparing the calculated vehicle behavior, measured tie rod axial force and measured steering torque to those of a track test using a prototype vehicle.

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INTRODUCTION

Drivers of an automobile feel the haptic force from the steering wheel. This force contains various information of a road and vehicle condition and it influences the judgment of the driver for next operation. Consequently, the steering torque is considered as an important factor for the vehicle driver to comprehend the road conditions and the running situation. On the other hand, the adoption of the electronic controlled steering system with new technologies has been extended as well as the assist control of the steering torque in recent years. New technologies include the active steering system which changes the ratio of the steering rack stroke to the steering angle in response to the operation of the driver to optimize the vehicle behavior for the driver. These electronic controlled steering systems have interactions with other complex vehicle subsystems such as electronic stability control system, and it is a hard task for the

vehicle developer to find the best solution from huge number of the combination of parameter settings with standard tools and test methods.

A Hardware-In-the-Loop Simulation (HILS) system for steering system can be one of the effective applications to solve this problem. The steering HILS system places the actual steering system inside the loop of a real-time vehicle dynamics simulation model and provides greater insight into the steering system and vehicle behavior effectively. In recent years, steering HILS systems have been proposed for the development of steering systems [1,2]. However, the accuracy of the tie rod axial force calculation that is an important factor to reproduce the actual track test should be improved because it is carried out by simple algebraic calculation using the knuckle arm radius and kingpin moment. The alignment of the wheel and tie rod is not considered in these studies.

The authors had developed a steering HILS system equipped with a five-channel steering test rig and a real-time simulator for the vehicle dynamics simulation and the tie rod axial force calculation [3]. In the steering HILS system, the vehicle dynamics simulation was carried out by using CarSim [4], which is a commercial software available for the real-time simulation. The tie rod axial force calculation was carried out by a multibody kinematics model of a strut suspension developed by authors. The kinematics model could co-work with CarSim and realize the tie rod axial force calculation by solving an inverse dynamic analysis of suspension and steering. The high accuracy of the tie rod axial force calculation of the kinematics model was confirmed in the off-line simulation and in the real-time simulation of the steering HILS system.

In this study, a multibody kinematic analysis was applied to a double wishbone suspension which is more complicated than the strut suspension. The evaluation of the steering HILS system with the kinematics model was carried out in two steps. First, the accuracy of the calculation of the kinematics model was evaluated by comparing the calculated tie rod axial force of the kinematics model with those of ADAMS [5], which is a reliable commercial software based on multibody analysis. The effect of the deflection of rubber bushes was also evaluated by comparing the result of ADAMS model with and without rubber bushes. Second, the evaluation of the steering HILS system with the kinematics model was carried out by comparing the vehicle behavior, measured tie rod axial force and steering torque with those of actual track tests.

STEERING HILS SYSTEM

Overview of Steering HILS System

The configuration of the steering HILS system with multibody kinematics model of front suspension is shown in Figure 1. In this system, the co-work of the test rig of the steering system with the real-time full vehicle simulation can realize the reproduction of a vehicle driving condition on the bench test. Multibody dynamics simulation software such as ADAMS is not suitable for a real-time vehicle dynamics simulation because of the high computational load. In the developed steering HILS system, the real-time vehicle dynamics simulation is carried out by CarSim, which is available for the real-time simulation by using a look-up table data of the characteristics of vehicle components. It can co-work with the test rig by replacing the steering rack stroke of the vehicle model by the measured rack stroke of the actual steering system on the test rig, and calculate the vertical displacement of the front knuckle and the tire force at the tire contact patch at the same time. However,

the calculation of the tie rod axial force is impossible by using CarSim because it is based on the look-up table data and therefore it does not calculate the interaction of suspension and steering parts.

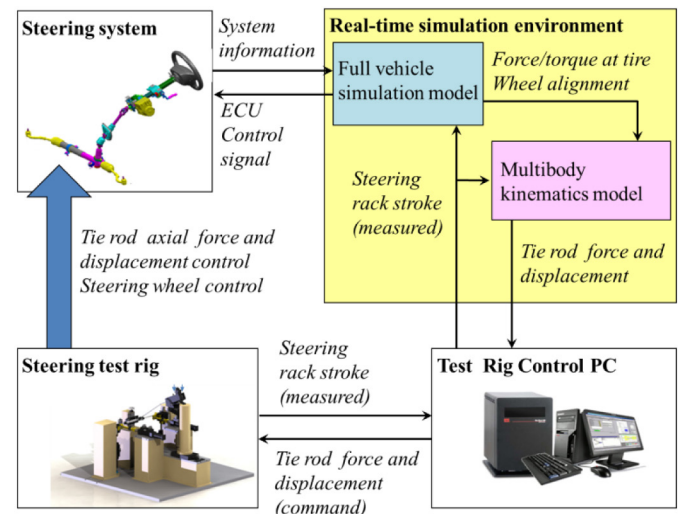


Figure 1. Configuration of the steering HILS system

The multibody kinematics model developed by authors can co-work with CarSim in MATLAB-Simulink environment. The kinematics model can calculate the geometry of the front knuckle by using the measured steering rack stroke on the test rig and the calculated vertical displacement of the knuckle in CarSim as driving constraints. In addition, the tie rod axial force is calculated as one of the constraint forces in the inverse dynamic analysis. The calculated tie rod axial force is used as the command signal for the steering test rig to reproduce the input of the steering system in the real-time simulation environment.

Steering Test Rig

The mechanical configuration of the steering HILS system is shown in Figure 2. The foundation of the steering HILS system is five-channel steering test rig. The five channels or degrees of freedom are comprised of a steering wheel input, two tie rod lateral inputs and two tie rod vertical inputs. The steering wheel input can be controlled in either torque or angular displacement by a steering input actuator; the lateral channels can be controlled in force or linear displacement while the vertical channels provide linear displacement control. The mechanical configuration of tie rod input is shown in Figure 3. The tie rod lateral input is accomplished through a bell crank arrangement incorporated into the vertical stage.



Figure 2. Mechanical configuration of steering test rig

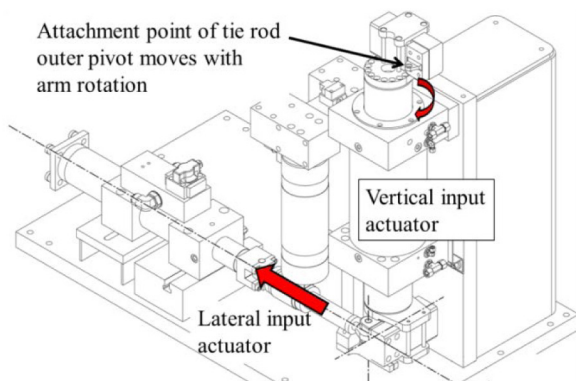


Figure 3. Mechanical configuration of tie rod input

MULTIBODY KINEMATICS MODEL

Overview of Multibody Kinematics Model

To ensure the accuracy of the tie rod axial force calculation, we have developed a multibody kinematics model of front suspension. In this study, the deformation of suspension metal parts, the play between the joints and the deflection of rubber bushes that connects the suspension parts in an actual vehicle are treated to be small enough to be ignored for the tie rod axial force calculation. Therefore, all joints between the suspension and steering parts can be expressed as holonomic kinematic constraint [6]. Furthermore, the inertia effect of the front wheels at steering input is also ignored because it is small enough in a usual driving condition with a quasi-static steering input and is much smaller than the tire force in an emergency handling condition with large and quick steering input.

The developed multibody kinematics model of front suspension is shown in Figure 4. The type of suspension is double wishbone. Six elements: vehicle body, right and left wheel and knuckles, right and left lower arms and steering rack are defined as independent rigid bodies. The remaining four elements: suspension upper arms and steering tie rods are all replaced by the distance constraint (massless link) to realize the high computational efficiency.

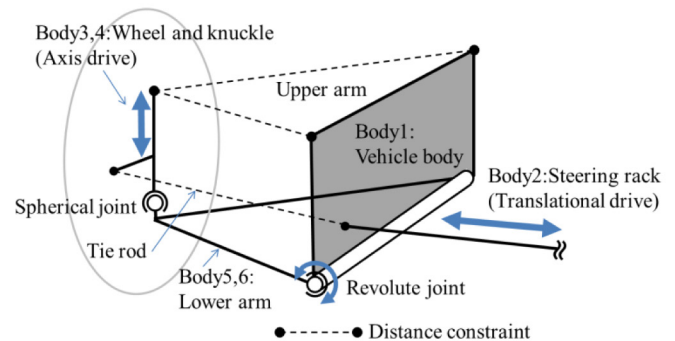


Figure 4. Overview of double wishbone suspension model

The constraints and the degrees of freedom of the developed multibody kinematics model are shown in Table 1. The number of bodies is six and each body has a six coordinate variables. Therefore the number of kinematic degrees of freedom of the suspension model is thirty six. On the other hand, the sum of the kinematic and driving constraints are equal in number to the number of the kinematic degrees of freedom, so kinematic analysis can be applied to this front suspension model.

Table 1. Constraints in multibody kinematics model of front suspension

Constraint	Connected / Related part		Number	DOF
Ground	Vehicle body	Absolute coordinate	1	6
Translational	Vehicle body	Steering rack	1	5
Revolute Joint	Vehicle body	Lower arm	2	10
Spherical Joint	Knuckle	Lower arm	2	6
Distance	Vehicle body	Knuckle	4	4
	Knuckle	Steering rack	2	2
Axis drive	Knuckle	Vehicle body	2	2
Translational Drive	Vehicle body	Steering rack	1	1
Total				36

The external force and moment acting on the wheels are calculated in the simulation process of CarSim, and the results are given to the kinematic analysis process. In addition, the vertical displacements of the wheels are also supplied by CarSim, which are treated as axial driving constraints in the kinematic analysis. The lateral displacement of the steering rack as a translational driving constraint is the measured steering rack stroke provided by the test rig. The multibody kinematic analysis process is described as a C-Mex S-function in MATLAB-Simulink environment to realize the co-work with CarSim in the real-time simulation environment.