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Full Vehicle Dynamic Modeling for Chassis Controls

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ABSTRACT – Most of reference models for chassis controls usually have low level degree of freedom like a bicycle model. However, these models include some different value in real vehicle motion and have a difficulty to adapt new technology. In addition, it is not good for real time that very high level degree of freedom like multibody dynamic analysis programs because of their long solving time. So, I developed adaptive full vehicle dynamic model that has 14 degree of freedom with theoretical equations and experimental data.

INTRODUCTION

Recently, development system of RCP (Rapid-Control Prototyping) Technology is adapted for the technology development of the electronic chassis control system. Therefore, a thesis of high fidelity real-time vehicle dynamics reference model is required. This paper studies technology for a thesis of vehicle dynamics model based on lumped parameter model to simulate driving characteristic of electronic control vehicle accurately. Matlab/Simulink based 14 DOF full vehicle model consists of modular white box vehicle models (horizontal direction, vertical direction) and black box vehicle models(tire characteristics, shock absorber characteristics). 14 DOF full vehicle model was compared with Carsim(the interpreter for vehicle dynamics) and real driving test(by KATECH – Korea Automotive Technology Institute) to verify the model.

INDIVIDUAL VEHICLE MODELS

In this paper, individual vehicle dynamics is represented white box and black box model. White box model is consist of horizontal, vertical model and black box modes have lookup table form. These individual models are module version.^{(1),(2)}

Horizontal Vehicle model

Horizontal vehicle model is 3DOF. It is consist of longitudinal, lateral translation, and rotation of vehicle mass center.

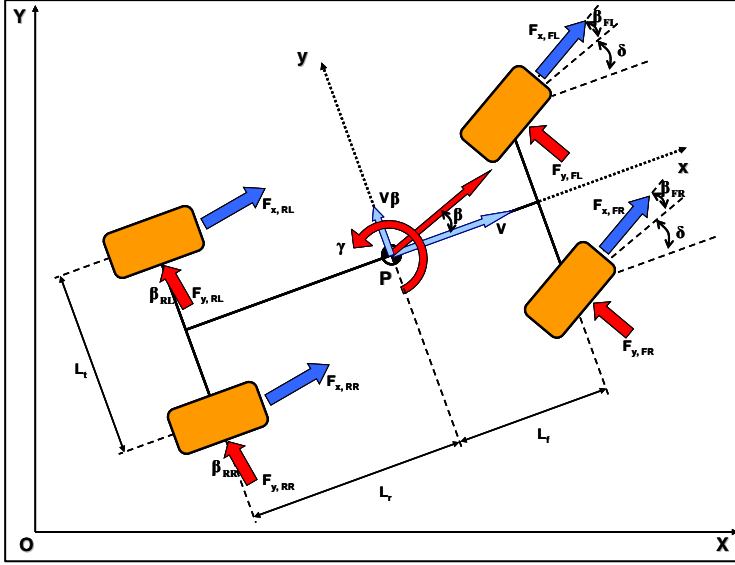


Figure 1: 3 DOF Horizontal vehicle model

$$m\ddot{x} = F_{x,FL} + F_{x,FR} + F_{x,RL} + F_{x,RR} \quad (1)$$

$$m\ddot{y} = F_{y,FL} + F_{y,FR} + F_{y,RL} + F_{y,RR} \quad (2)$$

$$I_{zz}\dot{\gamma} = L_f \left(F_{y,FL} + F_{y,FR} \right) - L_r \left(F_{y,RL} + F_{y,RR} \right) \quad (3)$$

(1)~(3) are horizontal dynamic equations and each symbols' means are table 1.

Symbol	Parameter
M	Vehicle total mass
\ddot{x}, \ddot{y}	Longitudinal axis acceleration, Lateral axis acceleration
F_x, F_y	Longitudinal and Lateral force at each tire
L_f, L_r	Front & Rear wheel base
I_{zz}	Vertical axis moment inertia
$\dot{\gamma}$	Yaw angular acceleration

Table 1: Horizontal vehicle model symbols

Horizontal model gets lateral force and longitudinal force from tire model. Based in these two forces, Horizontal model calculates Horizontal vehicle performance.

Vertical Vehicle Model

Vertical vehicle model is made of 7 DOF represented in figure 2. This model considers that 2 dimensions vertical dynamics, 1 track half car model for pitch dynamic and 2 track half car model for roll dynamic. So, This model has 3 DOF of mass center(vertical, roll, pitch dynamic) and 4 DOF of each wheel(wheel vertical dynamic).

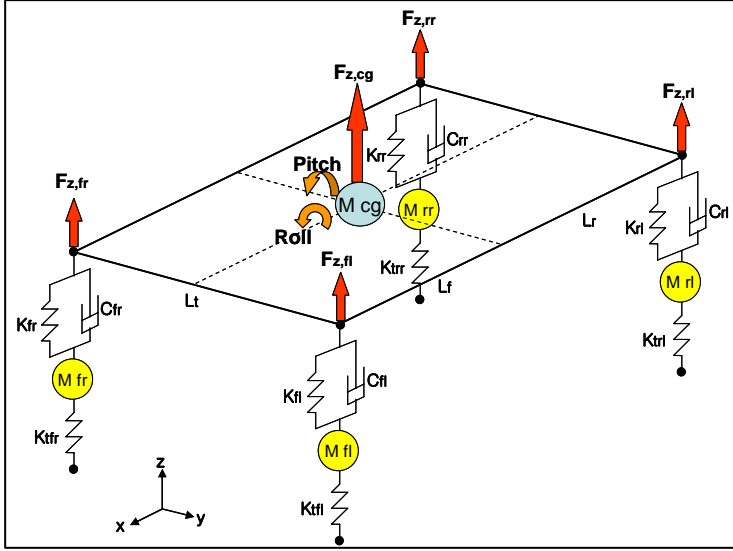


Figure 2: 7 DOF Vertical vehicle model

$$m_s \ddot{z} = F_{z,fl} + F_{z,fr} + F_{z,rl} + F_{z,rr} + M_{\theta,f} / L_f - M_{\theta,r} / L_r \quad (4)$$

$$I_{yy} \ddot{\theta} = -L_f F_{z,fl} - L_f F_{z,fr} + L_r F_{z,rl} + L_r F_{z,rr} + M_{\theta,f} + M_{\theta,r} \quad (5)$$

$$I_{xx} \ddot{\phi} = 0.5L_f F_{z,fl} - 0.5L_f F_{z,fr} + 0.5L_r F_{z,rl} - 0.5L_r F_{z,rr} + M_{\phi,l} + M_{\phi,r} \quad (6)$$

$$m_u \ddot{z}_{u,fl} = F_{z,fl} - 0.5M_{\theta,r} / (L_f + L_r) + 0.5M_{\phi,r} / L_f + F_{t,fl} \quad (7)$$

$$m_u \ddot{z}_{u,fr} = F_{z,fr} - 0.5M_{\theta,r} / (L_f + L_r) - 0.5M_{\phi,l} / L_f + F_{t,fr} \quad (8)$$

$$m_u \ddot{z}_{u,rl} = F_{z,rl} + 0.5M_{\theta,f} / (L_f + L_r) + 0.5M_{\phi,r} / L_r + F_{t,rl} \quad (9)$$

$$m_u \ddot{z}_{u,rr} = F_{z,rr} + 0.5M_{\theta,f} / (L_f + L_r) - 0.5M_{\phi,l} / L_r + F_{t,rr} \quad (10)$$

(4)~(10) are vertical dynamic equations and each symbols' means are table 2.

Symbol	Parameter
m_s, m_u	Sprung mass & Unsprung mass
\ddot{z}, \ddot{z}_u	Vertical acceleration at sprung mass & unsprung mass
I_{xx}, I_{yy}	Longitudinal & Lateral axis moment inertia
$\ddot{\theta}, \ddot{\phi}$	Pitch & Roll axis angular acceleration
$F_{z,fl}, F_{z,fr}, F_{z,rl}, F_{z,rr}$	Vertical force at each suspension
$F_{t,fl}, F_{t,fr}, F_{t,rl}, F_{t,rr}$	Vertical force at each tire

Table 2: Vertical vehicle model symbols

Vertical dynamic model calculates the vehicle vertical motion from road information, and pitch, roll motion from tire model using lateral, longitudinal forces. So, vertical force and vehicle vertical motion's characteristics are sent out output.

Tire Model

Tire model is 4DOF. It is basically consist of longitudinal 1DOF of each tire. To enhance the tire model's accuracy, this paper use black box form in figure 3. First and second figure show that characteristic data of 3-dimension related force and slip angle. 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 nonlinear black box model.

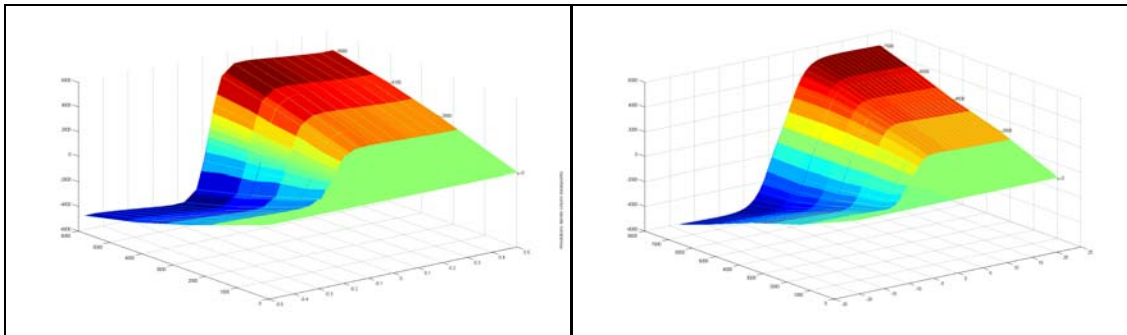


Figure 3: Nonlinear black box tire model ($F_x : F_z : \lambda$ & $F_y : F_z : \alpha$)

14 DOF FULL VEHICLE MODEL

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

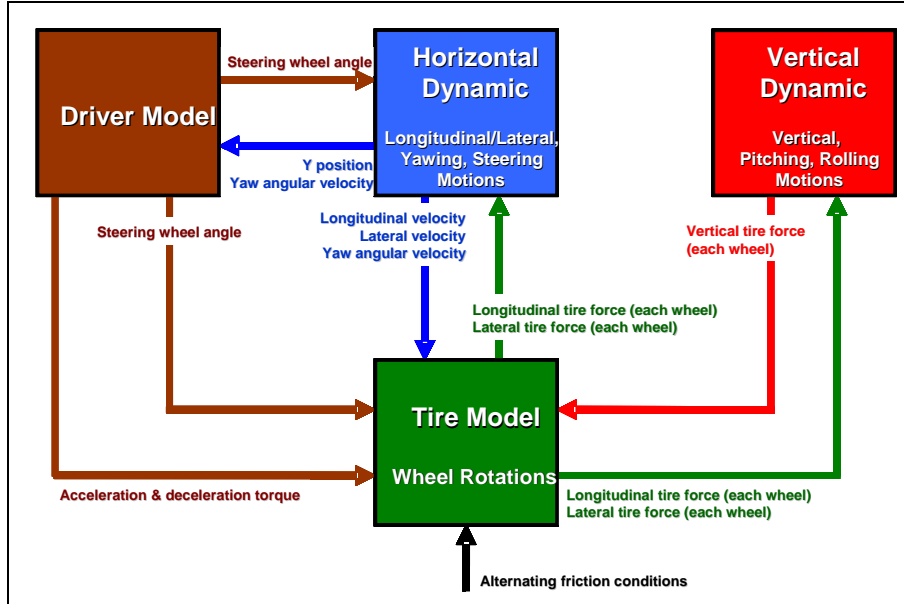


Figure 4: Modular architecture of vehicle model

Full vehicle model in Matlab/Simulink

14DOF full vehicle model based on Matlab/Simulink is individual motion module version in figure 5. It is easy to individual system's adjustment, repletion and understanding of signals.

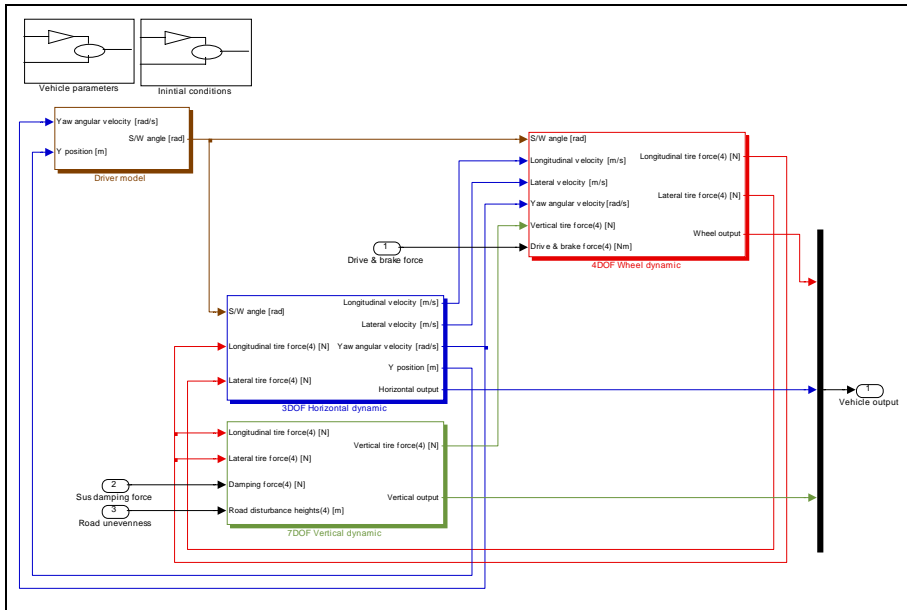


Figure 5: Modular vehicle model in Matlab/Simulink

Simulation Result

14DOF full vehicle model based on Matlab/Simulink is verified by using Carsim(vehicle dynamic analysis software), and practical experiment data which is conducted by KATECH (Korea Automotive Technology Institute). Figure 6 show that result of J-turn simulation of 14DOF model, Carsim and practical data in same condition.

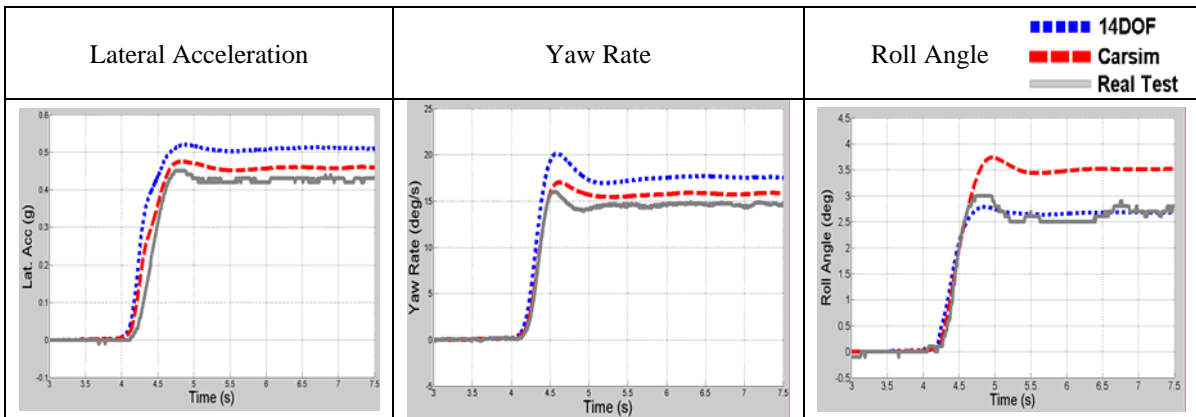


Figure 6: J-turn result (14DOF model vs Carsim vs Real Test)

Lateral Acceleration and Yaw Rate show that difference of 15%. Roll Angle which is representation of vertical motion is more accuracy than Carsim.

Figure 7 show that result of Single-Lane-Change simulation of 14DOF model, Carsim and practical data in same condition.

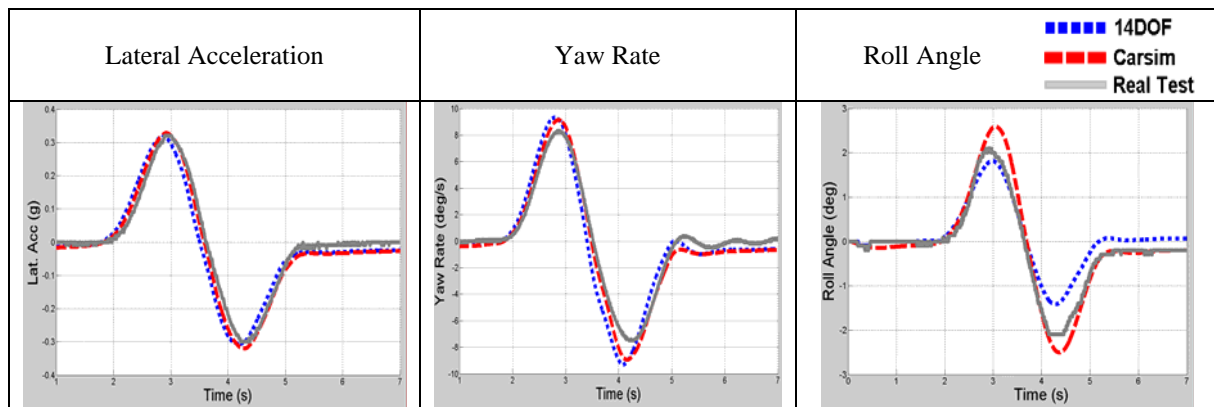


Figure 7: Single Lane Change result (14DOF model vs Carsim vs Real Test)

14DOF model show 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.

CONCLUSION

In vehicle control part, develop the 14DOF model. It is consider of whole direction of dynamic, and real time analysis is possible using less low DOF than commercial program. Also, individual dynamics link as module version each other so, expect the more accuracy result than existing simple control reference model. Afterwards, considering effect of suspension's kinematics and compliance, and calculating the real road condition will make more accuracy model.

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