Solutions Paper

Participating in the Autonomous Driving Control Benchmark Challenge

Our team (Dr. Junghyun Choi, Dr. Youngsik Jin, Dr. Dongyep Kang, Mr. Choongun Kim) participated in the IEEE CDC 2023 Autonomous Driving Control Benchmark Challenge held in Singapore last December. Various institutions organized the competition, including Modelon K.K., Chiba University, HIRANO Research Labo, Toyota Motor Corporation, and Sophia University.

In this challenge, participants are presented with benchmark problems related to controlling the motion and energy consumption optimization of a mobility vehicle equipped with four in-wheel motors (IWM).

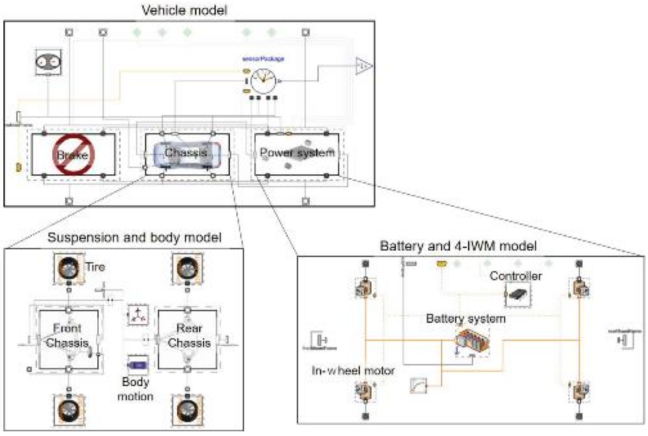
The challengers are provided with a 4-IWM EV simulator developed in Modelon Impact. A unit (FMU) of the vehicle model for connecting Modelica and MATLAB/Simulink has also been available. Challengers are required to design the controller directly using Modelica in Matlab/Simulink.

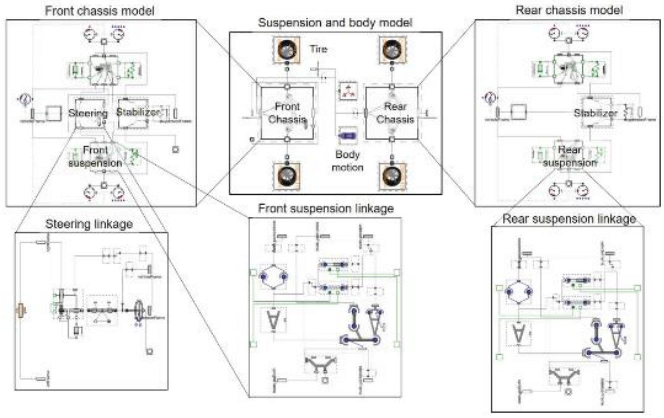
In these benchmark problems, participants need to address two main tasks:

1) Acceleration and braking on rough and slippery straight roads: Design a controller minimizing deviations in desired speed profiles, chassis movements (heave, pitch, roll), and energy consumption on bumpy and slippery straight roads.

2) Lane change on rough roads: Design a controller minimizing deviations from the desired course, chassis movements (heave, pitch, roll), and energy consumption during lane changes on rough roads.

The irregularities of the rough road given in the benchmark problem are not disclosed to the challengers, and the final evaluation is performed using various road irregularity patterns provided by the organizers. The evaluation format involves presenting the simulation results publicly through a poster presentation on the day of the competition.





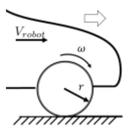
Approaches to solving the challenge problem

1) Acceleration and braking on rough and slippery straight roads:

- Applying slip ratio control to maintain a constant slip ratio between the wheels and the road surface.

- Describing limit values for the driving torque input to restrict excessive acceleration in the vertical direction.

- The fundamental formula for the slip ratio control applied in this competition is as follows:



$$\lambda = \frac{v_w - v_{robot}}{v_w}, \lambda_1 = \frac{\lambda}{1-\lambda}$$

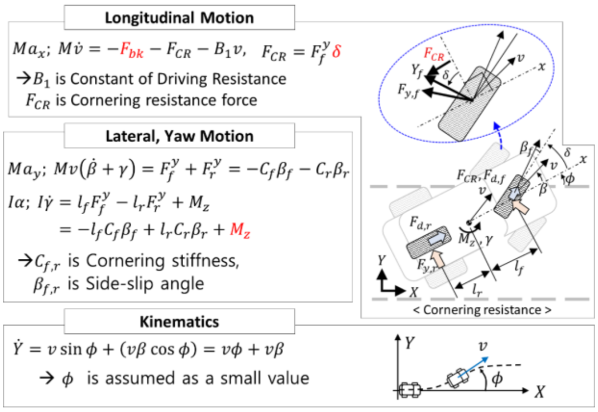
$$v_w = v_{robot} + \lambda_1 v_{robot} = (1+\lambda_1)v_{robot}$$

Here, λ is slip-ratio.

2) Lane change on rough roads:

To achieve the motion of lane change on rough roads, Model Predictive Control (MPC) was utilized, adhering to the ISO standards for dual lane change maneuvers. In particular, since the double lane change involves changing lanes according to a predetermined path, the given path and the corresponding vehicle trajectory were represented.

The cornering resistance concept was adopted to conserve driving energy. When formulating the objective function of MPC, this element was considered to design steering resistance reduction during cornering.



Fine-tuning is necessary for minimizing driving energy and enhancing stability during the vehicle's dual lane change. One method for achieving this involves generating Yaw Moment. For this purpose, a Gaussian Neural Network (GNN) was introduced. However, several issues were identified during the simulation phase in applying GNN, and as a result, conclusive results were not obtained for this competition. This aspect has been left as a subject for future research.

Results and review

Our team presented the simulation results in a poster titled "Enhancing vehicle stabilization in harsh driving conditions using model predictive control with neural network integration." The detailed pictures of the presentation on the competition day are as follows:

A total of 22 teams from around the world participated in this competition. Our team won the silver award.

To address the challenges presented in this competition, we utilized a car dynamics analysis simulator provided by Modelica. However, adapting to the slightly different aspects of the Modelica car model, such as port configurations, compared to the simulator we previously used (CarSIM) took some time. Nevertheless, we believe that Modelon Impact can easily and quickly modify input-output interfaces for car motion control and powertrain components through a web-based platform. As mentioned earlier, our team's challenges in applying GNN were attributed to their unfamiliarity with the Modelica model-based simulator. On the competition day, the Modelon team proactively addressed the issues we encountered and provided helpful explanations for future solutions.

Our team hopes to participate in the benchmark competition scheduled for 2024. In the next competition, we expect a developed algorithm to be successfully applied to the Modelica-based automotive simulation model.

Through this blog, we express our gratitude to Modelon for providing the car simulator, enabling us to explore various ideas to solve the problems presented in the competition.

Biography

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Jung Hyun Choi received the B.S. and M.S. degrees in mechanical engineering from Yeungnam University, South Korea, in 2010 and 2013, respectively, and the Ph. D. degree in the Department of Robotics Engineering, DGIST, South Korea, in 2021. He is currently a senior researcher at the Electronics and Telecommunications Research Institute (ETRI), Daegu, South Korea. His research interests include autonomous driving, vehicle dynamic analysis, and motion control.

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