A hierarchical controller design for the motion stability of four in-wheel motors actuated electric vehicles.

This blog proposed a hierarchical MPC-based control scheme to deal with the problems in the Benchmark Competition at the IEEE CDC 2023 conference. These problems require maintaining vehicle stability while accurately tracking the speed or trajectory of the vehicle. Using the Modelon Impact platform, engineers can conveniently design and simulate vehicle control algorithms.

MPC-based control scheme using Modelon Impact

What is MPC? Model predictive control (MPC) is a particular class of control. Its current control action is obtained at each sampling instant by solving a finite-time domain open-loop optimal control problem. The current state of the process serves as the initial state of the optimal control problem, and the solved optimal control sequence implements only the first control action. Model predictive control solves an open-loop optimal control problem. Its idea is independent of the specific model, but the implementation is model-dependent.

Modelon Impact is a systems design environment where the model is at the heart of all operations. It supports system-level modeling, simulation, optimization, and analysis to drive engineering insight and decision-making. Modelon Impact provides a graphical editor, customizable model libraries, model import capabilities, and solvers for dynamic and steady-state simulations. This functionality allows efficient and collaborative work within the Modelon Impact environment.

4-IWM vehicle model of Benchmark Problem

The vehicle dynamics control for 4-wheel IWM vehicle is assumed as the benchmark problem. The 4-IWM vehicle model is provided by Modelon Impact. It has been shown that a 4-IWM vehicle can control the driving/braking behavior and the body attitude by controlling the vertical reaction force at each wheel caused by anti-squat geometry and anti-squat geometry of the suspension. This benchmark problem is formulated to control both the vehicle driving state and body attitude with minimum energy consumption by independently controlling the torque of the four IWM of each wheel.

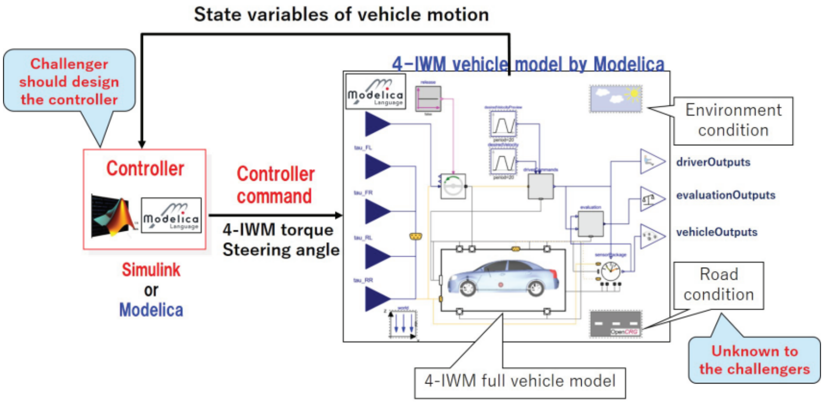

Fig.1. 4-IWM vehicle model of Benchmark Problem

Problem 1: Acceleration and braking on a rough, slippery, straight road

The Task of acceleration and braking on rough, slippery, straight road is given as the Problem 1. The vehicle is requested to follow the desired speed profile, as shown in Figure 2.

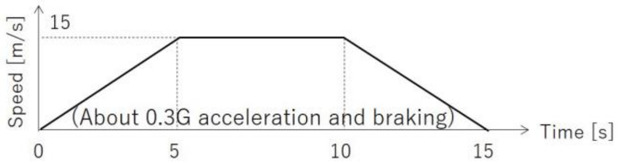

Fig. 2. Desired vehicle speed profile for the Problem 1

Our team constructed a three-degree-of-freedom vehicle dynamics model based on the bicycle model. We selected the vehicle's longitudinal speed, front wheel rotational speed, and rear wheel rotational speed as state variables.

$$M v_x = F_x - F_r - F_w$$

$$F_w = \frac{1}{2}\rho A C_w v_x^2,\ F_r = C_r * F_z$$

$$I_w \omega_f = T_f - F_{xf} R,\ I_w \omega_r = T_r - F_{xr} R$$

And based on the above control-oriented model, we designed the control system as follows.

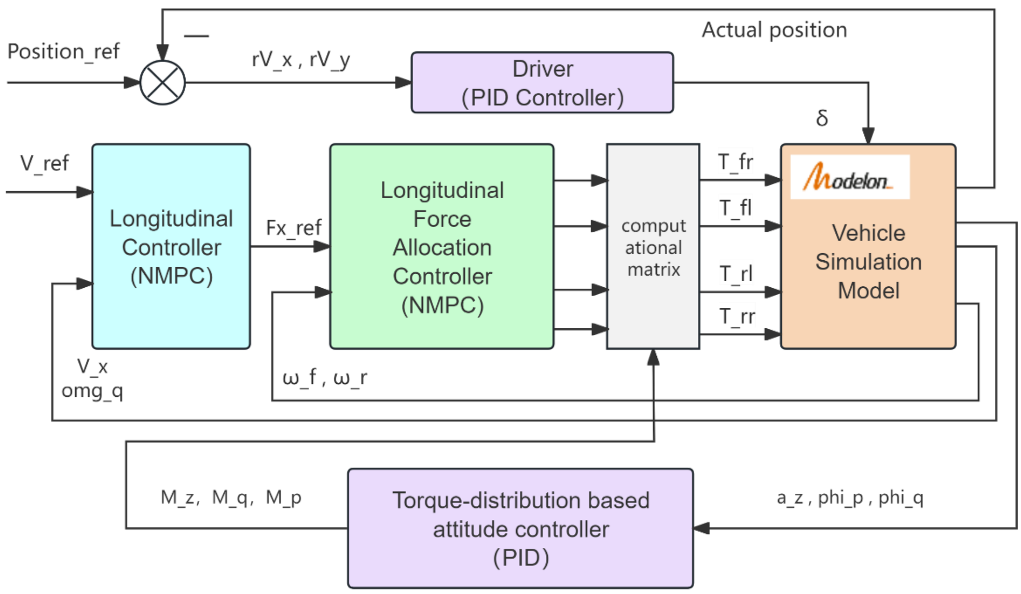

Fig.3. Control Flowchart for the Problem 1

Based on the NMPC algorithm, we constructed a Longitudinal Controller. Energy consumption, comfort, and longitudinal speed tracking performance are comprehensively considered in the optimization performance metrics. An online optimization algorithm solves the current optimal longitudinal force in real-time during the vehicle motion process. The total longitudinal force is distributed to all four wheels in the longitudinal force distribution controller. At the same time, the NMPC algorithm optimizes the four wheels' input torque required to generate the corresponding longitudinal force.

Simultaneously, a torque-distribution-based attitude controller based on the PID algorithm is designed. This controller calculates the magnitude of the adjustment torque required to maintain vehicle stabilization from the motion state fed back by the model. By this method, attitude stability was successfully maintained during vehicle operation.

In this way, the longitudinal dynamics stability control was realized, and the actual speed fluctuation under the constant speed demand in speed tracking was less than 0.04m/s.

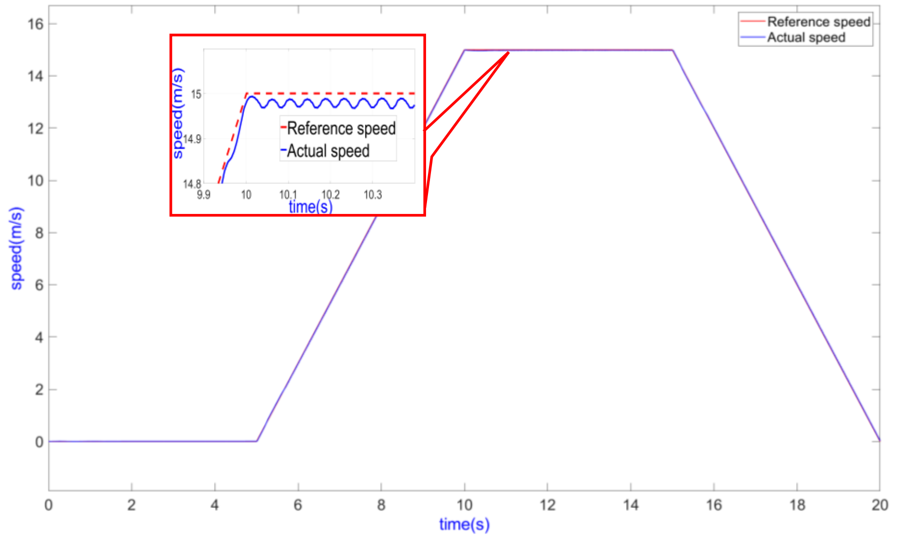

Fig.4. The simulation result of speed tracking

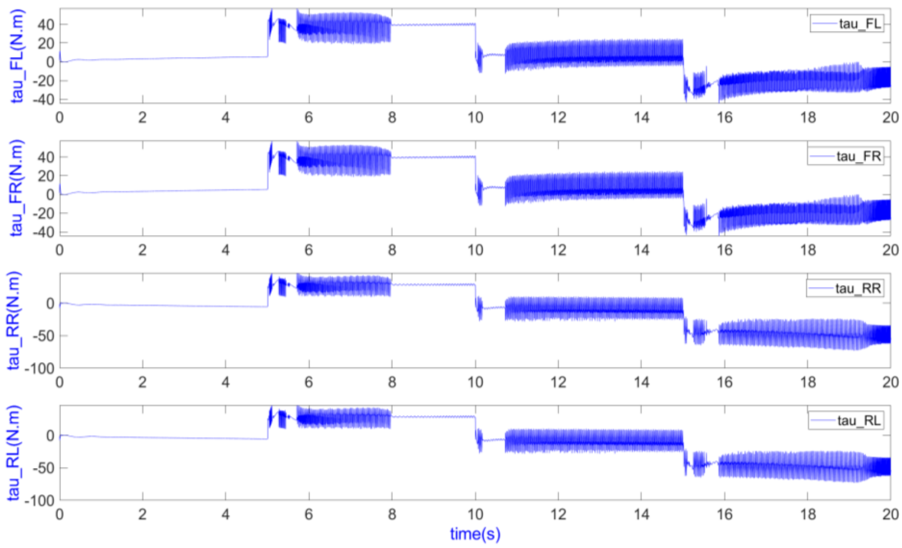

Fig.5. The input torque for the Problem 1 control system

Problem 2: ISO double lane change on rough road

The ISO double lane change on a rough road is given as Problem 2. It is requested that the vehicle follow the desired path of ISO double lane change course at vehicle speed of 60[km/h].

For the vehicle's lateral dynamics stability control problem (Problem 2), we took the angle after making a difference between the ideal trajectory position and the actual position. We calculate the ideal turning angle by the ideal trajectory position and the actual position, then use the PID controller to control the input steering wheel angle. Thus, the lateral trajectory can be controlled. For longitudinal trajectory tracking, we choose the same control methods as Problem 1, where the longitudinal controller is used to solve for the optimal longitudinal force. Then, the longitudinal force allocation calculates the required input torque for the front and rear wheels.

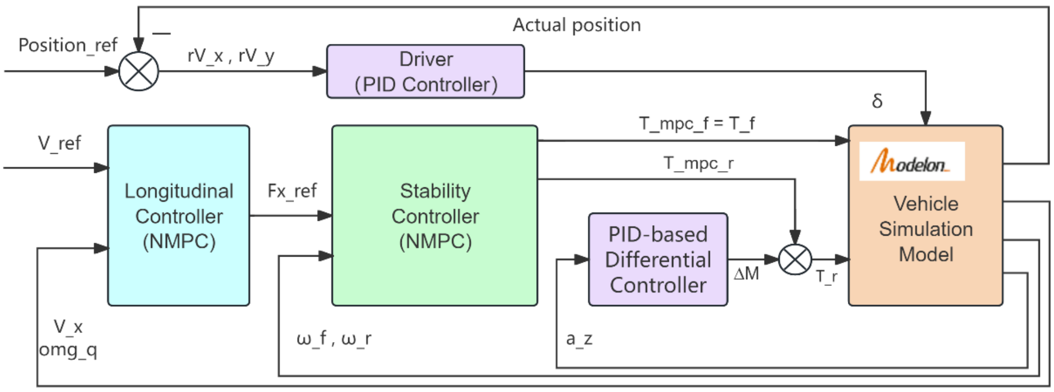

Fig.6. Control Flowchart for the Problem 2

However, considering that vehicles driving at high speeds on undulating road surfaces generate severe vertical vibrations, We choose to use the difference between the vertical acceleration output from the model and the reference value as the input to the PID-based differential controller and then calculate the vertical adjustment torque and sum it with the input torque calculated by the longitudinal force distributor as the input torque of the final four wheels, which improves the vertical stability of the vehicle while guaranteeing the performance of the longitudinal speed tracking.

By the Modelon Impact platform, we simulate our control system on the target 4-IWD vehicle. The result shows our control system ensures that the vehicle's ISO trajectory is tracked accurately while maintaining the stability of the vehicle's attitude.

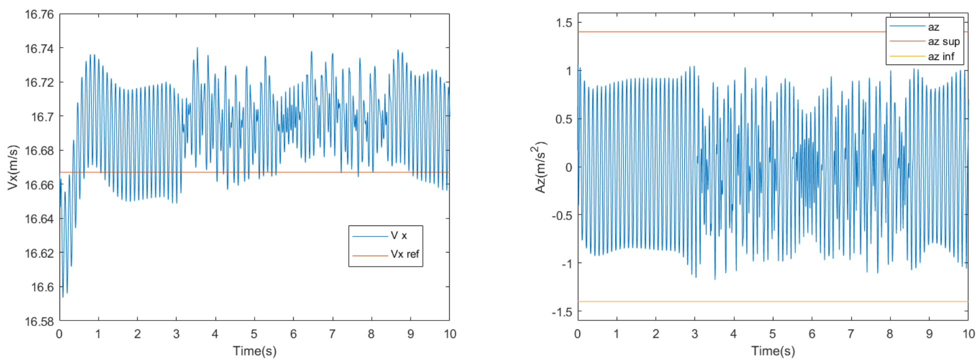

Fig.7. The simulation result for the Problem 2

Conclusion

The above proposed controller is validated in the official simulation platform (**Modelon Impact**). The simulation results demonstrate the effectiveness of the proposed control scheme and show that our control system can maintain vehicle stability while accurately tracking the speed or trajectory of the vehicle.

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