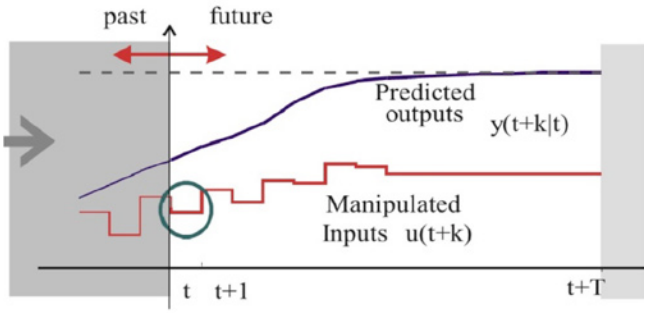
Addressing Automotive Industry Needs with Model Predictive Control

The automotive industry is facing significant hurdles as it strives for dramatic improvements in fuel economy, reduced emissions, vehicle safety, and overall positive driving experience, including automated driving. Advanced control technology is recognized as a key enabler for overcoming these challenges; however, further advances in control research will be needed before solutions can be commercialized.

The automotive domain poses demanding control system requirements: control loops need to be able to operate in milliseconds, the computational infrastructure is limited to an embedded controller, and stability, robustness, and performance must be maintained over millions of individual vehicles and for hundreds of thousands of kilometers driven under vastly different climate and operating conditions.

Recent advances in the theory, algorithms, and synthesis methods of model predictive control (MPC) have attracted considerable interest from the automotive industry. Although production applications are rare (if any), this attractive and intuitive method has shown considerable promise in applications ranging from R&D prototypes to fully functional production-like vehicles. Significant results have been achieved, but numerous opportunities exist for further research and development.



Three Examples of Automotive Challenges for Advanced Control

Cornering and Stability Control

Advanced control facilitates effective active front steering (AFS) and optimal coordination with differential braking (DB) for superior vehicle cornering and driver assistance. Such control can greatly enhance handling and stability, especially in adverse weather conditions when operating the vehicle/tires in extreme nonlinear regions.

Idle Speed Control

Idle speed control (ISC) is one of the most basic and representative automotive control problems and is still one of the most important aspects of engine operation. The main objective is to keep the engine speed as low as possible for superior fuel economy while preventing engine stalls. Critical factors of ISC are limited actuator authority and time delays in the control channels.

Energy Management for Hybrid Vehicles

In hybrid electric vehicles (HEVs), the energy stored in the battery can be used by electric motors to supplement the engine. With the aid of an advanced controller, the HEV energy management system decides optimal power distribution under practical operating constraints.

MPC Basics

MPC operates by repeatedly solving a constrained optimal control problem initialized at the current estimate of the system state (see figure above). The formulation incorporates a system model, operational constraints, and a user-defined cost function. The use of the current state in the repeated optimization results in feedback that increases robustness with respect to open-loop optimal control.

Advances in MPC technology, increased computational power of electronic control units, and increasing performance, safety, and emission requirements have attracted interest from the automotive industry. Key relevant advantages of MPC are the capability of handling constraints on inputs and states, the intuitive design, even for multivariable systems, and the ability to define control objectives and relative priorities by cost function.

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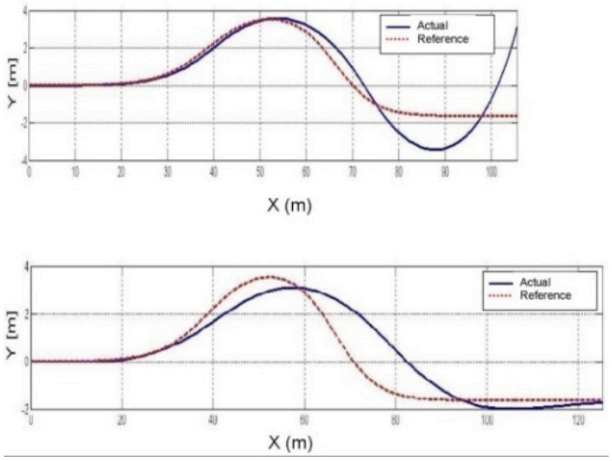
Enhanced Driving on Snow

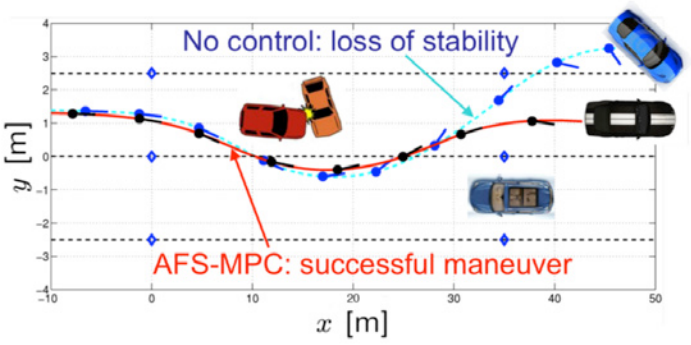
MPC can be used to exploit a model of the lateral vehicle dynamics to select optimal actions for steering and braking, hence achieving superior yaw rate tracking and overall vehicle cornering performance. Research prototype MPC controllers have been developed and tested on slippery surfaces. Results from road tests for double lane change (DLC) maneuvers on snow surfaces are shown below.

Autonomous AFS



The reference (red) and actual (blue) DLC trajectories on snow at 55 kph are shown for a fixed PID gain steering robot designed for asphalt surfaces (top) and for an MPC system that incorporates vehicle stability state constraints (bottom). Neither car has electronic stability control. The MPC anticipates that aggressive steering could lead to loss of traction, thus trading off its initial tracking error for future gains and successful completion of the DLC maneuver.

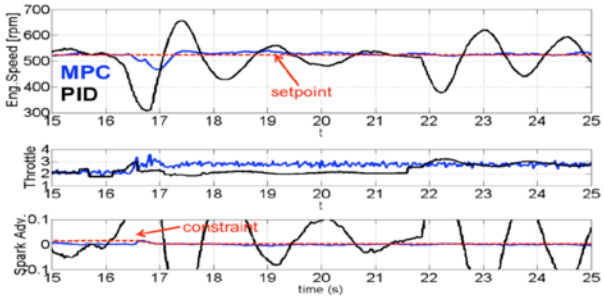
Driver Assist AFS/DB Coordination



DLC with (black and white car) and without (blue car) MPC-based driver assistance that coordinates active front steering and differential braking. The test executed on a snowy road at approximately 50 kph shows that MPC helps the driver to enlarge the car operating envelope. (In both cars, electronic stability control was disabled for this test.)

Disturbance Rejection for Idle Speed Control

MPC is attractive for ISC because it is capable of dealing with limited actuator authority and time delays. In tests, a multi-input, multi-output (MIMO) MPC controller outperformed conventional controllers by optimally coordinating the constrained control channels and handling the delays, and anticipating loads through the predictive model.



Disturbance rejection of MPC-ISC (blue) and conventional PID-based ISC (black) on a V8 engine. In this test, the AC compressor turned on after the power steering pump was already fully engaged. As a result, the spark authority was heavily reduced to avoid knocking, but MPC maintained control by adjusting the action on the throttle.

Power Smoothing for HEV Batteries

Battery management controllers have been developed for various HEV configurations. For a series HEV configuration, the MPC controller exploits the battery power to smooth engine transients, thus achieving more efficient operation. The MPC smooths transients while guaranteeing battery state-of-charge and respecting power constraints with superior tradeoff between steady-state and transient efficiency. The MPC controller was implemented in a fully functional series HEV prototype and evaluated in standard fuel economy (FE) tests, showing sizable FE advantages.

Future Directions

MPC has shown significant potential in several automotive applications, but several challenges remain before its use in production vehicles is widespread. These include further mitigation of the computational effort, especially for nonlinear optimization, easy-to-use tuning methods, as well as theoretical development and tools for stability, robustness, and performance guarantees.

For more information: D. Hrovat, S. Di Cairano, and H.E. Tseng, I.V. Kolmanovsky, The development of model predictive control in automotive industry: A survey, Proc. IEEE International Conference on Control Applications, 2012.