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Energy conservation in vehicle operation by solution of mixed integer optimal control problems

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Energy optimal operation of vehicles like trucks or subway trains often requires the offline and real-time numerical solution of state and control constrained optimal control problems with both continuous and integer controls.

In the talk, two rigorous mathematical solution approaches, powerful numerical methods and practical applications for this class of problems are described.

The indirect approach based on Pontryagin's Maximum Principle and the Competing Hamiltonians algorithm leads to intricate multi-point boundary value problems in state and adjoint variables with jumps and switching conditions possessing difficult stability properties. An expansion of the adjoint variables and the local optimization of the Hamiltionian can be exploited to construct optimal feedback strategies even in case of integer controls.

A direct approach based on outer convexification, relaxation and the Krein-Milman theorem allows for offline solution of mixed integer control problems with no integer gap while avoiding the combinatorial explosion of computing time. Moreover, arbitrarily good approximations by integer solutions with finitely many switches can be constructed by adequate rounding procedures. Based on these offline solutions fast optimal feedback strategies are developed using Real-Time-Iterations for Mixed-Integer Nonlinear Model Predictive Control.

Advanced Multiple Shooting methods for the numerical solution of the intricate boundary value problems as well as optimization boundary value problems in both the indirect and the direct approach are described.

Applications to energy optimal operation in long-distance drives of heavy duty trucks and cam-controlled subway trains in the New York subway system demonstrate the high potential for energy conservation.

The talk is based on joint work with Hans Georg Bock, Christian Kirches, Richard W. Longman and Sebastian Sager.