- modelling and simulation
- control design
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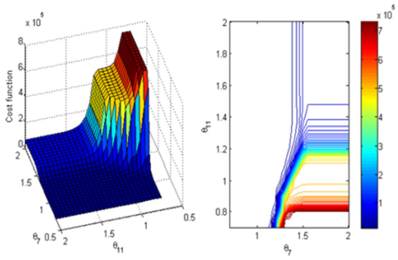
industrial systems and control

Distributed Economic MPC for Vehicle Platoon Control



The use of Distributed control based on Economic Model Predictive Control (MPC) for vehicle control is briefly summarized in the following. The Economic MPC and Distributed optimal control paradigms are presented. The application of these methods in coordinated vehicles control is considered.

Economic MPC

The cost-function of conventional Model Predictive Control (MPC) problems is normally defined so that closed-loop responses and sensitivity functions can be easily tuned. There are very few occasions where the cost-function has a physical significance and represents a quantity to be optimised. This is not a weakness of predictive control but is normally the case in most optimal control design problems. It is therefore unlikely to be an adequate representation for managing real-time plant or process operation with respect to the economic performance.

The effects of nonlinearities and constraints may also be significant in economic optimization problems. A positive deviation from a target may represent a profit, whilst a negative deviation from a target may represent a loss (or vice versa). For example, consider an input that supplies heat energy to a reactor (e.g., a steam jacket). Supplying more steam to the jacket than the target is more costly in terms of the energy consumption of the reactor, whilst supplying less steam consumes less energy. There are therefore problems in using linear system models and “least squares” or “quadratic cost function” control problem constructions to solve economic optimization problems.

This mismatch between standard MPC results and practical needs resulted in calls to unify process economic optimization and process control needs in a “tailored” theory. The idea of using an economic cost functions directly in an MPC scheme emerged and has led to a significant research effort. The resulting MPC scheme is called economic MPC (EMPC). EMPC minimizes an arbitrary economic cost objective directly, which does not necessarily penalize the tracking error to the optimal target, as opposed to minimizing the deviation from a set-point in some norm. Since EMPC accounts directly for process economics which is aligned with the core ideas of next-generation manufacturing (e.g., Smart Manufacturing, market-driven manufacturing, and real-time energy management) its popularity amongst researchers has significantly increased.

Distributed MPC

The key to the success of MPC is the inherent flexibility of the policy, which allows for complex issues such as constraints or delays to be dealt with explicitly. Despite this, the control of large-scale, interconnected or networked systems (e.g. a platoon of vehicles, or electricity network) still presents significant difficulties to MPC. For example, the organizational structure of the system and its information flows may not be conducive to a centralized control approach suggested by standard MPC. Moreover, even if it is, the MPC optimization problem for the whole system may be too large to simulate or solve on-line. In Distributed MPC (DPMC), the optimal control problem is decomposed into several smaller sub-problems that are distributed to a set of local controllers or control agents. Each controller or agent is responsible for controlling a subsystem composed of a subset of the system states and control inputs. In order to achieve system-wide stability and satisfactory closed-loop performance, the agents exchange information so that they can coordinate their decision making. Many schemes have been proposed to date, and differ according to the particularities of the scenarios in which they are applied: for example, the way in which the system is decomposed, the source of coupling, or the limits in the communication or computational capacity.

Industrial Systems and Control Ltd.

ISC Ltd. works across industrial sectors and has gained wide experience in a range of applications. It is this peripheral vision which is valuable for automotive companies, which have a complete understanding of current advances in the automotive industry. ISC Ltd. has particular expertise and experience on the following areas and methodologies:

- Physical system modelling and simulation, including training simulators.
- Developing tailored optimal or predictive control solutions for real-world applications.
- Production of bespoke estimation and filtering algorithms for nonlinear control.
- Use of stochastic or robust controls for different industries like wind energy and marine.
- Design of Machine Learning algorithms for industrial and embedded domains.
- Training courses mostly for the automotive industry based in the US.

Our Expertise

- **In-depth understanding of control technologies**
- **Extensive experience in diverse industrial applications**
- **High-fidelity modelling of system behaviour**
- **Expert analysis of complex problems**
- **Proven project management and research skills**

Our Core Competencies

- **Dynamic modelling & simulation**
- **Control strategy design and implementation**
- **Optimization**
- **Algorithm development**
- **Benefits analysis and technology review**
- **Research & Development**
- **Troubleshooting**
- **Training**

Our Philosophy

- **Approaching problems with an open mind**
- **Dedicated to identifying practical and innovative solutions without compromising performance.**
- **Imparting understanding and empowering clients to drive improvements themselves.**

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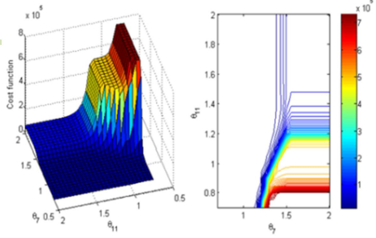


Platooning Control of Connected Vehicles

The Problem

Since most operating costs of vehicles are fuel costs, the improvement of fuel efficiency will noticeably increase profits for many organizations. The formation of vehicle platoons should reduce the overall fuel consumption. Furthermore, vehicle platooning is viewed as one of promising approaches to improve road safety and more effective road usage. Different topics and technologies are involved in vehicle platooning, e.g. network control, the influence of inter-vehicle communications and the fuel economy on urban roads. Unfortunately some very practical problems such as collision avoidance, vehicle stability and energy management cannot be solved efficiently by standard centralized control problem frameworks.

Distributed Economic MPC for Platooning Control of Connected Vehicles

Distributed MPC for vehicle platooning has been analyzed, exploiting the information sharing capability of modern connected vehicles. These solutions involved robust policies and constraints for handling external disturbances and enforcing stability, however, economic aspects were not included. The use of EMPC has been considered recently and is promising to improve fuel economy. The main advantage of the EMPC in vehicle platooning control is the opportunity to extend the performance to that the DMPC can achieve, whilst at the same time maintaining the problem within a predictive control framework. The main difference is due to the ability of the distributed approach to split the problem between different vehicles, whereas the usual EMPC is formulated as a centralized control problem. Due to the use of dual decomposition methods, the EMCP problem for vehicle platooning control is split in a distributed optimization form. This can be solved using the original DMPC paradigm, but including the EMPC advantages.

The Advantage

- The platooning control problem (and potentially any connected vehicle control problem) can employ a well-known MPC framework, including new economic features.
- The structure of the distributed control problem can easily accommodate the structure of the distributed problem for the set of vehicles involved in this driving scenario.
- The computational complexity of the initial distributed MPC is similar to the resulting economic approach.

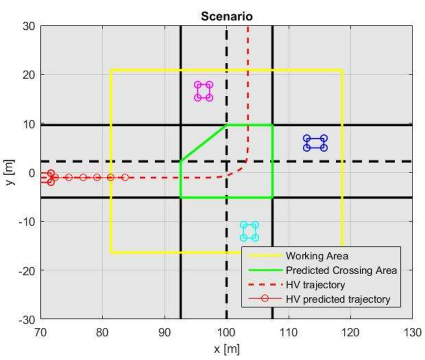
ISC Expertise in Automotive Control and Optimization

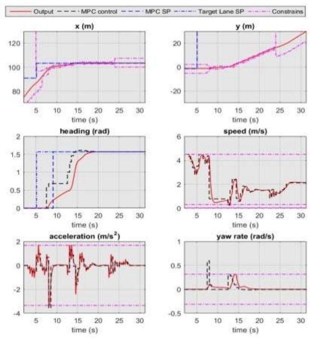
ISC Ltd has been involved in the last years in different research and development projects involving both universities and automotive companies.

In particular, considering AV control, activities of ISC involved the design and development of different advanced control system for autonomous vehicles. Main activities and research area have considered the capability of AVs to face uncertain and unpredictable traffic scenario for guarantee the safety of passengers and satisfying prescribed control target. Due to its capabilities on advanced control theory and optimization, developed solutions permitted to evaluate worst case scenario performance, addressing both theoretical and practical issues in the control system design.

ISC is expert in the development of MPC and optimal control system able to optimize the control performance of any dynamic system, including cars and autonomous vehicles. For reaching this target, different advanced techniques have been considered and their potentiality exploited and customized. Nonlinear optimization, computational efficient modelling, advanced data-driven and model-based techniques have been considered and used for developing different complex and performable control system.

ISC Control of AVs by computationally efficient nonlinear MPC method





Proposed activities give a possible approach for directing possible activities involving the autonomous vehicles featured by an electric/hybrid drivetrain. Further, several bespoke solutions and studies could be evaluated for evaluating advantages and limits of this type of vehicle. Expertise of ISC on advanced control techniques and their application in the automotive field permits extend the research horizon overcoming the state-of-the-art of the technique, for matching different needing of the single customer.

Clients Include

- **Torotrak: variable transmission system.**
- **Visteon: applying LabVIEW to automotive power control.**
- **General Motors: SI engine control.**
- **General Motors: SCR system identification.**
- **General Motors: Control model calibration.**
- **Toyota: Diesel engine control.**
- **Cummins: Diesel engine design methods assessment.**
- **Ford: Autonomous vehicle control.**
- **FCA: Training Activity via Electronic throttle design study.**
- **NXP: Hybrid Electric powertrain control.**

Recent Automotive Training Courses

- **Ford at Dearborn annual courses between 2004-2019**
- **Cummins at Columbus, 2018**
- **Toyota at Ann Arbor 2014 & 2018**
- **Chrysler at Auburn Hills 2011-2016**
- **Freescale in Glasgow and Detroit 2008**
- **NXP in Glasgow 2018**
- **GM Detroit 2015**
- **Jaguar in Coventry and Gaydon 2006 & 2009**
- **Riccardo in Leamington and Shoreham 2006 & 2009**
- **Visteon in Detroit 2004**

"Approaching a problem with an open mind is an important aspect of the ISC philosophy, as is using the simplest, most cost-effective solution."

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