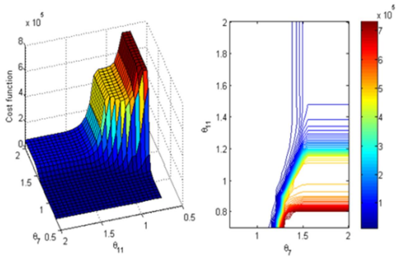

Electric Powertrain Control

Electric vehicles (EVs) and Hybrid Electric vehicles (HEVs) have gained attention over the past decade as one of the promising ways to reduce greenhouse gasses. In this document control topics for pure EVs are discussed, according to the experience of Industrial Systems and Control Ltd. This document considers the hot topic of pure EVs control.

Pure Electric Powertrain

Pure EVs have different characteristics with respect to HEVs, due to the presence of one or more electric energy storage units and the absence of any alternative power generation systems. The EV drive train consists of three major subsystems: electric motor propulsion, energy source, and auxiliary. The electric propulsion subsystem comprises the vehicle controller, power electronic converter, electric motor, mechanical transmission, and driving wheels. The energy source subsystem involves the energy source, the energy management unit, and the energy refueling unit. The auxiliary subsystem consists of the power steering unit, the hotel climate control unit, and the auxiliary supply unit.

A general control system for EVs considers the structure: based on the control inputs (accelerator and brake pedals positions), the vehicle controller provides control signals to the electronic power converter, which functions to regulate the power flow between the electric motor and energy source. The backward power flow is due to the regenerative braking of the EV and this regenerated energy can be restored into the energy source, providing the energy source is receptive. Most EV batteries as well as ultracapacitors and flywheels readily possess the ability to accept regenerative energy.

The EV control system is composed by a low-level layer, to drive the power electronic subsystem, and the high-level supervisor, designed for improving the overall vehicle performance, because fuel efficiency depends on current data and future data. In other words, this high-level controller usually comprises event-based or time-based conditions that coordinate the component level operation. This level should be designed according to an optimization approach (e.g. MPC). Further topics in EV control are vehicle parameters estimation, definition of active safety and energy efficiency control, battery modelling and estimation, four-wheels independent control of the vehicle and smart grid integration.

Electric Vehicle Control Topics

Here, different aspects involved in the control of pure Electric Vehicles are given, briefly presenting different paradigms to be used for addressing the control problems.

- **Stability Control.** The stability control is a problem affecting pure EVs featuring different electric motors driving independent wheels (e.g. front and rear wheels). The problem would consider different aspects over the vehicle stability, for example enforcing constraints on the power distribution. Limitations related to most common policies would be reduced by the use of modern predictive policies, These have advantages, for power consumption reduction and, the possibility to mitigate the problem by using model-based methods able to reduce the controller design and calibration effort.
- **State-of-Charge Estimation.** State of charge (SOC) is simply a measure of how much current the battery can deliver after partial discharge or charge. Classical techniques consider direct measurement, book-keeping estimation and Model-based methods. Recently alternative approaches have been proposed, e.g., modern data-driven Machine Learning and Artificial Intelligence methods. Those techniques address different problems affecting classical algorithms and their effect on the battery SoC estimation problem highlight advantages and critical aspects.
- **State-of-Health Estimation.** The performance of a battery when it is connected to a load or a source is based on the chemical reactions inside the battery. The chemicals degrade with time and the usage reflects the gradual reduction in the energy storage capacity of the battery. Methods considered for State-of-Health evaluation are similar to SoC estimation, enabling the use of mixed model-based and AI methods.
- There is a wide set of problems a **Battery Management System (BMS)** should consider. For example, battery temperature control and safety. These and other goals are usually faced by ad-hoc BMS systems developed according to a set of rules related to the type of battery. Limits of this type of BMS would be overcome by using model model-based predictive policies, to optimize the performance of the battery, increasing its remaining useful life-time with a limited effort required for design and development.

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 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**

Regular Reporting

On most projects, we have the following reporting arrangements:

- *A webinar held typically every 3 weeks.*
- *A mid-project face to face meeting.*
- *End of project technology-transfer workshop, held a few weeks before the end of the project so that corrections and updates can be made.*

ISC Limited
36 Renfield Street
Glasgow G2 1LU
Scotland UK

t +44 (0) 141 847 0515
f +44 (0) 141 221 1706
e iscmail@isc-ltd.com
w www.isc-ltd.com

Industrial Systems and Control Ltd. wholly owns and manages Applied Control Technology Consortium
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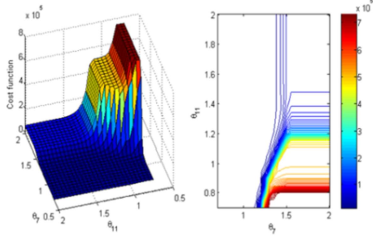
applied control technology consortium

- modelling and simulation
- control design
- system troubleshooting
- technology transfer and training
- energy efficiency investigation
- software tools

industrial systems and control



Industrial Systems and Control Ltd.

Industrial Systems and Control (ISC) Ltd., was set up almost 30 years ago to provide technology transfer between the University of Strathclyde' Industrial Control Centre and industry.

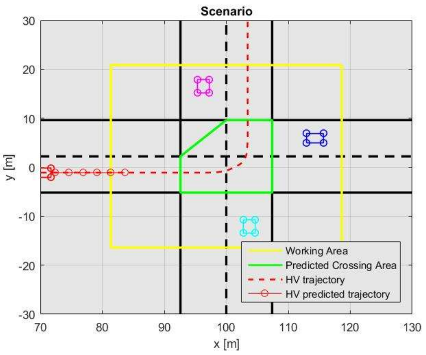
ISC Ltd., works across industrial sectors and has gained wide experience in a range of applications. It is this peripheral vision which is valuable for automotive companies, which have a complete understanding of current advances in the automotive industry, but might gain from design and technological advances in other sectors.

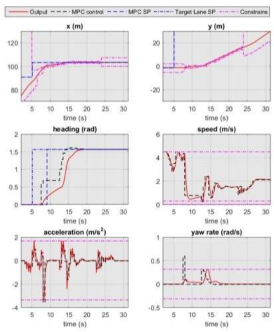
ISC Ltd. has particular expertise and experience on the following areas and methodologies:

- 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.

ISC Expertise in Automotive Control and Optimization

Over the last 2 decades ISC Ltd has been involved in several research and development projects with both universities and companies. The development of advanced control systems represents the main services provided by ISC for optimizing the behavior of a system. The collaboration between ISC and automotive field companies has been consolidated in a multitude of projects, activities and training courses, establishing partnerships during the last 20 years. ISC expertise covers techniques for modelling and controlling automotive systems and sub-systems such as vehicle's dynamics control and the development of models/controllers for vehicle subsystems, e.g., engines, autonomous vehicles, HEVs/EVs.





ISC Control of AVs by computationally efficient nonlinear MPC method

ISC has large expertise in the development of MPC and other optimal control systems for a variety of applications and industries, including autonomous and non-autonomous vehicles. Various advanced modelling and control techniques have been considered and their potential exploited and customized – these include nonlinear optimization methods, computationally efficient modelling, advanced data-driven and model-based control techniques.

ISC has been involved in the study and development of a wide set of activities for vehicles powertrain modelling and optimization. In general, vehicles are composed by a set of complex subsystems. In order to provided nominal and/or best performance, vehicles components should be controlled by appropriate policies, developed using modern techniques, e.g., model-based design or machine learning algorithms.

Among the wide set of projects ISC has been involved for modelling and controlling vehicle subsystems, different activities considered powertrain control and optimization. ISC has developed different control algorithms for optimizing complex engines and powertrain performance in a computationally efficient way by use of nonlinear predictive controllers. The modelling of complex automotive systems has also been considered by ISC, developing high fidelity simulation and control-oriented models based on modern artificial intelligence techniques, e.g. (Support Vector Machines or Neural Networks). Advanced identification and modelling techniques have been applied to develop bespoke solutions for some of the most common modelling problems, e.g., noise and disturbances affecting data used for identification or grey/black-box identification of models for control.

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

ISC Limited
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Glasgow G2 1LU
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t +44 (0) 141 847 0515
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e iscmail@isc-ltd.com
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