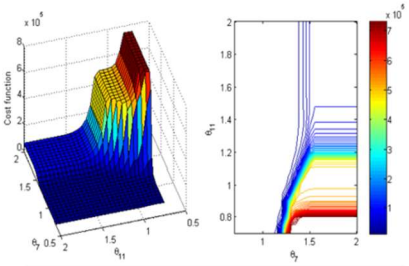
- modelling and simulation
- control design
- system troubleshooting
- technology transfer and training
- energy efficiency investigation
- software tools

industrial systems and control



Digital Twin for Electric Vehicle

This document briefly reviews the main concept of Digital Twin (DT) paradigm exploited in the automotive field, with a focus on Electric Vehicle (EV) propulsion system monitoring. EVs are equipped with several electro-mechanical components subject to degradation that would be monitored to ensure safety and reduce the cost of ordinary maintenance of the electric car. By exploiting the connectivity capabilities of modern EVs, the DT paradigm can be exploited to develop systems able to evaluate and anticipate fault/failures of vehicle components by combining DT simulation information and real-world vehicle data. Industrial Systems and Control (ISC) Ltd., has expertise in advanced control systems, developing sophisticated algorithms able to observe and optimize the performance of a system, including modern hybrid/electric vehicles and related subsystems, e.g. batteries.

Remaining Useful Lifetime

EVs sensible components (e.g., batteries or electric motors) are subject to degradation and potentially to faults and malfunctions that can reduce the nominal performance of the car and its expected safety. The degradation of such components would be evaluated during the lifecycle of the vehicle by comparing reference data generated by a DT with real-world information provided by the car. Such a huge amount of data would be processed to evaluate the instantaneous date of health of the system in analysis. By combining information provided by these different sources of data, a Machine Learning (ML) algorithm would be able to provide information about the Remaining Useful Lifetime (RUL) of the components and the instantaneous subsystem Failure Rate (FR). These indices would permit to condense the state of health of an EV subsystem in a single number and act in advance to prevent failure of the single component.

EV Propulsion System Digital Twin Monitoring

ISC developed a DT-based system to evaluate the capabilities of a monitoring system using ML techniques to estimate the RUL and the FR characterizing EV propulsion system subject to faults affecting sensors, thermal insulation and bearings of car electric motors. The developed system permits to evaluate the capabilities of such a type of monitoring system to detect introduced faults on the real-world vehicle model and related effects in terms of FR and RUL. To guarantee the effectiveness of the developed demonstration system, faults and vehicle components have been modelled by considering real-world components and datasets characterizing fault-free and faulty scenarios.

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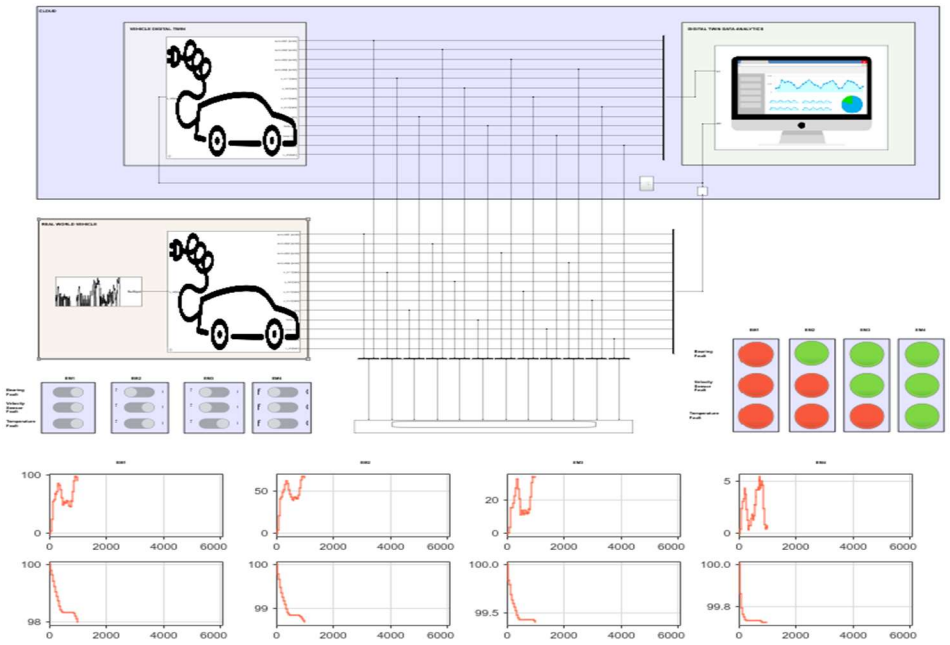

Digital-Twin Simulation System of EV Propulsion System

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 find practical and innovative solutions without compromising performance.**
- **Imparting understanding and empowering clients to drive improvements themselves.**

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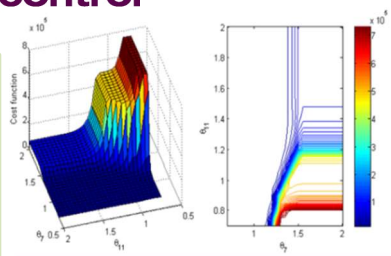


Digital Twin Technology

Digital Twin (DT) technology was defined in 2012 by the National Aeronautics and Space Agency (NASA). It is a virtual representation of a production system that can run on different simulation systems that are characterized by the synchronization between the virtual and a real system. This is thanks to sensed data and connected smart devices, mathematical models, and real-time data elaboration.

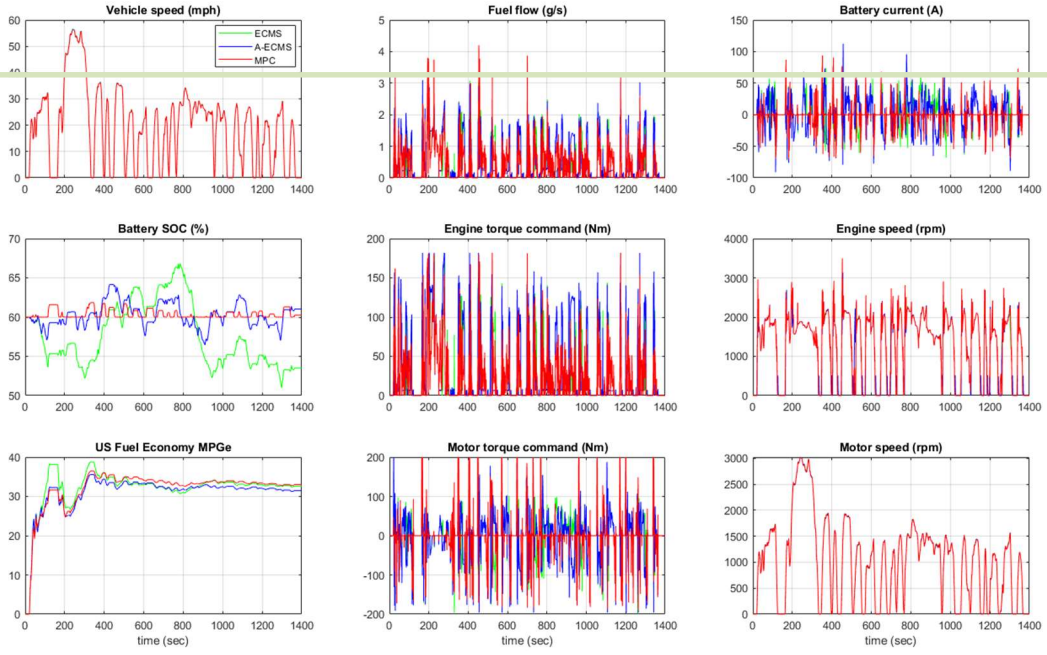
In the last years, DT solutions have been proposed in research and industrial applications as promising solutions to different problems. According to the focus of the DT-based system developed, DT can be classified in several ways, including DT for production, DT for predictive maintenance or DT for design. These, and other types of DT solutions exploit possibilities given by the high degree of connectivity of real-world systems and, capabilities of ML and Artificial Intelligence (AI) techniques to handle huge sets of heterogeneous data. In particular, in the automotive field, DT technologies look really promising to overcome the limits of common on-board vehicle monitoring systems.

The experience of ISC on AI and ML combined with the in-depth knowledge of model-based techniques permits to develop and test different kinds of DT-based systems for automotive and several other fields, to develop advanced DT systems able to optimize and improve the performance of any kind of connected real-world system.

ISC Expertise in Automotive Control and Optimization

Over the last 2 decades ISC has been involved in several research and development projects with both universities and companies. The development of physical models and advanced control systems represents the main service provided by ISC to study and design ad-hoc solutions for optimizing the behavior of a system.

HEV Control FTP75 Driving Cycle Test: A-ECMS vs ECMS vs MPC developed by ISC



The collaboration between ISC and automotive field companies has been consolidated by a multitude of projects, activities and training courses, establishing a partnership with many international companies over the last 20 years. ISC expertise covers strong knowledge on techniques for modelling and controlling automotive systems and sub-systems, considering vehicle's dynamics control and the development of models/controllers for different types of vehicle subsystem, e.g., engines, autonomous vehicles, and HEV/EV controls.

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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