Data-Driven Systems Engineering

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The problem

Climate change, the Covid-19 pandemic and the urgent need for a sustainable co-existence between humans and the environment is likely to accelerate the digital transformation for complex critical infrastructures such as water, food, transport and electricity.

The resilience and sustainability of these complex infrastructures relies upon the acquisition and analysis of data with unprecedented spatial and temporal resolution, the application of advanced modelling, optimisation and control methods, and the integration of multiple disciplines and expertise to develop solutions.

Recent advances in data analytics are impacting the way we engineer systems, creating unique challenges and unmatched opportunities, advancing theory, methods, tools and practice of data-driven design. Data, typically from networks of distributed sensors and actuators, can help enhance designs, optimise performance, provide timely warnings of failures, support automation and make better use of resources. Yet current SCADA (Supervisory Control and Data Acquisition), IoT (Internet of Things) and IT systems, key to the timely, reliable and secure delivery and access to data, are not designed with the rigour, reliability and agility to meet the needs of multiple applications and users in order to maximise investment returns. This gap brings many research challenges, the most important of which is the co-design of both the computing (SCADA/IoT/IT) and engineering infrastructures.

How research addresses this

Our research explores the gap between engineering infrastructures and computer systems engineering and in doing so focuses on the notion of cyber-physical interaction. Take the next generation water networks, which dynamically adapt their connectivity and hydraulic conditions in order to improve resilience, minimise leakage, reduce energy use and carbon emissions, and respond to incidents such as pipe breaks (e.g. change network connectivity to avoid interruptions to supply). The design and control of such dynamically adaptive water supply networks led to the development of novel monitoring and control technologies, and their integration with advances in hydraulic modelling and mathematical optimisation. Currently, the main challenge is the near real time and large-scale implementation of the developed technologies and methods in complex operational systems. For example, how could we guarantee the reliable, secure, accurate and timely provision of large volumes of data, and also the actuation of control valves, from a distributed system in near real-time via unreliable radio networks, and battery operated sensor and actuation systems, which operate in a rather hostile environment (e.g. frequently flooded underground manholes).

What we have achieved so far

Through several projects (e.g. the NEC Smart Water network project), we have developed monitoring and control technologies, hydraulic modelling and mathematical optimisation methods for the design and operation of dynamically adaptive networks. We have implemented these methods in five water distribution networks in England. We have been working on the scalability of this approach to deliver unparalleled controllability and observability of water supply networks in order to improve their resilience and address multiple operational objectives. Our methods and technologies have ben also deployed during the Covid-19 pandemic to ensure the resilient supply of water to critical customers (e.g. the Nightingale hospital in Bristol).

A key task to address the scalability challenge is the reliable, secure and timely acquisition of data. We were first to build a low-powered wide-area radio communications protocol that can provide the guarantees required to support slow-feedback control of systems (e.g. water supply networks).

In addition to the management of water supply networks, and as part of the Lloyds Register Foundation/Alan Turing Institute “Data Centric Engineering” Programme, we are examining how decentralised near-shot machine learning can drive wireless actuators to support rainwater collection in Singapore and how sensor systems can provide early yield detection for precision farming in English Vineyards. Working with the PeTraS IoT Hub and the Tate we are building security protocols for real-time logistics. Our Industry 4.0 work designs sensor systems that carry out on-board machine learning for factory automation optimisation, asset management and predictive maintenance via RF Shadowing. Indeed, our RF Shadowing work is allowing us to reuse the communications radio as a sensor, sensing things like rotational machines, water content of grapes or indeed liquid changes in human lungs. Returning to cyber-physical interaction, our EPSRC programme grant, S4 Science for Sensor System Software, has been exploring tools and methodologies, such as verification, formal analysis, to provide systems engineers with guaranteed reliable or correct systems.

Future directions and long-term vision for impact

Our ultimate ambition is that through the understanding of cyber-physical interaction, systems engineering design will automatically involve the co-design of the computer and physical systems in tandem in highly challenging complex engineering and commercial contexts.

The long-term vision is that such approaches, tools and methodologies will produce technologies and systems that can solve the large societal issues - the greater resilience and sustainability of infrastructures such as transport, food production, water and energy provision.

Technological novelty can provide levels of secure autonomy for infrastructure only if we have the science to better understand how the technology behaviour and be able to provide guarantees.

Find out more – publications and links:

Infrasense Labs http://www.infrasense.net/

Data-Centric Engineering - Alan Turing Institute / Lloyds Register Foundation https://www.turing.ac.uk/research/research-programmes/data-centric-engineering/data-centric-engineering-challenges

Example project on enhancing critical ecosystems https://www.turing.ac.uk/research/research-projects/enhancing-critical-ecosystems

Example project on using data science in retrofit https://www.turing.ac.uk/research/research-projects/retrofit-design-built-environment