Institution: Kingston University

Unit of Assessment: 15, General Engineering

Title of case study: Application by transport industry of advanced control algorithms for fast mechanical systems

1. Summary of the impact (indicative maximum 100 words)

The application of advanced control algorithms has generated an impact on the economy and the environment through increased precision and reduced cost of operation of fast mechanical systems. A reduction in fuel consumption and CO_2 emissions has been achieved in the transportation industry by the implementation of novel advanced control algorithms for advanced cruise control systems.

2. Underpinning research (indicative maximum 500 words)

The underpinning research is the development of optimising, high accuracy control algorithms for implementation in fast sampling systems with limited computing resources. For high accuracy, optimal energy control of systems with constraints, a prominent control method is Model Based Predictive Control (MBPC). MBPC is less computationally intensive than direct optimisation methods, but still requires a lot of computational power when dealing with non-linear and constrained systems.

The reduction of computational requirements for optimising algorithms, especially for MBPC, has been an active area of research for many years, in many research groups worldwide. Especially significant in providing background to this research are the works of Prof. Tomizuka (Berkeley), Prof. Kouvaritakis (Oxford) and Prof. Richalet (ADERSA).

The contribution of Kingston's Industrial Control Research Group is in the adaptation of the state-dependent state-space models for representation of the system dynamics and constraints, including switching systems too. This has enabled embedding the problem in the class of linear time-varying optimisation problems, which can be solved using an analytical approach, hence reducing the computational burden. Another contribution is in the Dynamic Linear-Quadratic Predictive Controller with improved stability and optimality properties for finite horizons. Furthermore, the group has developed dynamic programming algorithms for efficient optimisation over short horizons. More recently, further enhancements have been made to the theoretical algorithms. Those include the use of an alternative model structure (local linearization), stability analysis, application to switching systems and theoretical analysis of preview function/controller.

The researchers involved are:

Academic staff members: Prof. A. Ordys (Head of School, 2006-present), Dr. J. Karwatzki (Principal Lecturer, 2006-2009), Dr. A. Curley (Senior Lecturer, 1996-present), Dr. O. Duran (Senior Lecturer, 2009-present), Mrs G. Collier (Principal Lecturer, 2006-present), Dr. J. Deng (Senior Lecturer, 2011-present)

The work on application of those algorithms in different industries has been continuous since 2006. The application areas considered over that period of time include: defence and security (Ordys, Collier, Duran), manufacturing (Karwatzki, Curley, Ordys), automotive - vehicle dynamics (Ordys), power generation (Ordys), automotive – engine and powertrain control (Ordys, Collier, Deng, Duran).

In these application areas, the commercial implementation of the algorithms is at different stages of development.

3. References to the research (indicative maximum of six references)

1. Ordys A., M. Tomizuka and M. Grimble, State-space Dynamic Performance Preview/Predictive Controller, Transactions of the ASME, Journal of Dynamic Systems, Measurement and Control, Vol 129, No 2, pp 144-154, March 2007

2. Shawky A., A. Ordys, L. Petropoulakis and M. Grimble, Position Control of a Flexible-Link Manipulator Using Nonlinear H∞ with State-Dependent Riccati Equation, Proceedings IMechE, Part I: Journal of Systems and Control Engineering, Vol. 221, pp 475-486, 2007

3. Shakouri P., A. Ordys and M. R. Askari, Adaptive Cruise Control With Stop&Go Function Using The State-Dependent Nonlinear Model Predictive Control Approach, ISA Transactions, 51 (5), 622-631, 2012

The following research projects have been selected to illustrate the research underpinning the impact:

Title:	***Industrial Nonlinear Control and Real Time Applications***
	Sponsor: EPSRC (Platform Grant)
Award:	£400,000
Dates:	May 2005 to May 2010
Highlights**:**	The project was a Platform Grant awarded to ICC at Strathclyde. The project continued strategic research into non-linear control, but emphasis was given to real time implementations and applications. This part was supervised by Ordys. Kingston University become involved in the project when Ordys joined the University in 2006 and started developing algorithms for automotive and defence applications.
Title:	***Fuel Consumption Reduction with Predictive Control Algorithms in Trucks***
Sponsor:	MAN Nutzfahrzeuge AG
Award:	EURO 20,000 (approximately)
Start date:	2007
Highlights:	MAN Trucks were attracted to the algorithms developed at KU and decided to invest in implementation of these algorithms for optimisation of fuel consumption in trucks. The project is looking at the use of 3D maps, satellite positioning systems together with advanced control algorithms to minimise fuel consumption. MAN have provided funding for a PhD student, travel expenses, engineering time – one person at ½ FTE working on the project plus testing facilities – exclusive use of a vehicle for a period of approximately ½ year to perform on-road tests.

4. Details of the impact (indicative maximum 750 words)

The work on application of MBPC algorithms in different industries has continued in Kingston since 2006. Several application areas have been considered as described above. In those application areas, the commercial implementation of the algorithms is currently at a range of developmental stages. The most advanced application is in automotive power train control.

In automotive power-train applications, the theoretical results stimulated collaboration with MAN Truck & Bus AG in Germany. The project started in 2007 and has now reached the stage when the implementation of the algorithms has been successfully completed and the fuel savings have been documented.

In extensive trials performed by MAN, the system achieved fuel savings of between 6.5% and 8.3%. Their estimate of the average fuel saving over their total fleet of vehicles on the European motorway network is 4%.

Based on these test results, MAN began to introduce this system into their trucks and buses in early 2013. With yearly production of long distance vehicles at MAN being around 30,000 vehicles, and average fuel consumption of these vehicles being 38,700 litres/year, the estimated fuel savings are approximately 1550 litres/year per long distance vehicle. This amounts to over 46 million litres per year for the long distance fleet.

Economic benefits include the reduction of the costs of public transport and transportation of goods.

Environmental impacts are emission reductions of around 4%.

Two patents have been granted, in collaboration with MAN:

1. DE102005050540A1 Optimisation for ecologic and economic operation of vehicles
2. Vehicle parameter adaption Predictive speed and gear adaption for vehicles EU 1792810s

5. Sources to corroborate the impact (indicative maximum of 10 references)

1. Corroborating statement from Senior Development Engineer MAN Truck & Bus AG
2. Corroborating contact: Senior Development Engineer MAN Truck & Bus AG

The above sources can corroborate all aspects of the impact.