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Editorial for Special Issue Dedicated to Sir Alistair G.J. MacFarlane

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Abstract

This special issue of the International Journal of Control is dedicated to Sir Alistair MacFarlane. It contains a collection of papers on systems and multivariable control contributed by a number of people, including ex-students and collaborators of Alistair, or those who know Alistair's work, reflecting his diverse interests. During his time in Cambridge, Alistair was Editor of the International Journal of Control.

Editorial

Alistair MacFarlane was throughout his career interested in applications problems as well as in the modelling and control theories that were relevant to their solution. For Alistair the problems came first, and it was his search for solutions that produced his thirst for mathematics and his life-long interest in multivariable feedback. Whilst we might want to claim that the papers in this volume were carefully selected to reflect his philosophy and spread of interests, this would be only partially true. Instead, we asked a number of people who have worked with Alistair, or who know Alistair's work, if they would like to contribute to this special issue of the International Journal of Control. We were just lucky to receive a portfolio of papers that reflect rather well his diverse interests. Alistair was Editor of the International Journal of Control while he was in Cambridge and thus this Journal seemed a natural venue for publishing this Volume.

In the 1960s when Alistair was in his early career optimal control, optimal design and state-space theory were a focus of attention for control theorists. It was also a time when the benefits as well as the short comings of these theories were being considered. This dichotomy was succinctly captured in H. H. Rosenbrock's 1971 paper "Good, bad, or Optimal". Rosenbrock was a practicing chemical

engineer, and it was his informed skepticism that led to a resurgence in the development of frequency response design methods, the generalization of these ideas to multivariable systems, and the development of the fundamentals of algebraic systems theory that underpinned them. MacFarlane was a contemporary of Rosenbrock in the Control Systems Centre in UMIST, Manchester, but came from an electrical engineering background with a strong interest in both state-space and frequency response methods. The links between transfer functions and state-space methodologies were central to many aspects of his work. Geometry, linked to state space theory, was crucial to the way he approached many problems.

For organizational reasons we have divided the papers into four groups of roughly equal size. Following on from Alistair's personal reminiscences relating to multivariable feedback, which opens the volume, five papers on system theory related topics are presented. These papers are followed by papers on Control in Mechanics, Optimal Control and Estimation and Model-Predictive Control.

The first of the papers by Karcanias develops the algebraic and geometric theory of invariants for singular systems using the theory of minimal bases for matrix pencils. It is shown that the singularity of the system leads to a partitioning of the controllability indices. The algebraic and geometric aspects of this partitioning are investigated and alternative systematic procedures for their computation are developed. The use of matrix pencils as the tool unifying the algebraic and geometric properties of state-space descriptions goes back to the work he did with MacFarlane. This work aims to link state-space (i.e. geometric), frequency response and algebraic methods. This work is also linked to the classical algebraic work of Rosenbrock based on the use of system matrices and matrix pencil theory, and has the geometric influence of MacFarlane's approach to system analysis.

Karcanias' second paper deals with the linear part of the *Determinantal Assignment Problems* (DAP) that was introduced to unify all frequency assignment problems (poles and zeros) in linear systems under different compensation schemes. The DAP may be studied within an exterior-algebra algebraic-geometry framework and has as a linear part the study of *polynomial combinants,* which is considered here. The spectral assignability of *dynamic polynomial combinants* is studied using the properties of *Generalized Sylvester Resultants.* The results provide a general treatment of the spectrum assignment problems and gives a solution to the minimal design of problem of polynomial combinants. MacFarlane's drive to bridge the algebraic and geometric approaches to systems theory motivated the introduction of the algebro-geometric DAP framework that is examined in this paper.

Alistair has always had a strong interest in the control theory underpinning the solution of practical problems, with the study of stability using frequency response methods fundamental to his work. Vinnicombe presents a new result on the robust stability of feedback systems. The paper deals with a class of systems that can be approximated in the graph topology by real rational transfer function matrices. In his paper he shows that for finite-dimensional linear systems the robust topology is a weaker topology than the graph topology in which feedback stability is a robust property.

Li, Xu and Lin present an up-to-date review of advances in the stability testing and feedback stabilization of discrete multidimensional systems. They consider advances in the stability testing and stabilisation of linear multi-dimensional discrete systems in the frequency domain, as well as the parameterisation of all stabilising compensators for stabilisable multi-dimensional systems.

As is evident from his book on Dynamical System Models (1970), the modelling of dynamic systems and the use of graph-based methods for the simulation, analysis and design of control systems has throughout his career been a key interest of Alistair's. De Silva and Alipourazadi extend the application of linear graphs to multi-domain dynamic systems using a unified representation of

mechanical, electrical, thermal, and fluidic systems. It is shown that linear graphs are well suited to mixed-domain modelling and that Thevenin and Norton equivalent circuits can be extended to mixed-domain systems.

Closely allied to Alistair's interests in optimal control and state-space theory are his interests in analytical mechanics and circuit theory. As is well known, mechanics is a subject that was close to the heart of other past members of the Cambridge applied mathematics and control dynasty including Routh (and his son G R R Routh), Maxwell and Whipple, and more recently Coales and Fuller. The links between analytical mechanics and optimal control are of course legendary, with the links between optimal control and circuit theory more recent and probably less well known. The second group of three papers relate to the relationships between mechanics, circuit theory and optimal control. The paper by Perantoni and Limebeer begins by reviewing an optimal-control based solution of to the classical brachistochrone problem. This analysis is then extended to the case of a rolling body that is constrained to roll along a least-time curve, which is shown to comprise a central cycloidal section embedded between hypergeometric initial and terminal portions. A three-dimensional nonholonomic rolling body problem is then solved using numerical optimal control.

Pires, Smith, Houghton and McMahon investigate the trade-offs relating to the design of energy regenerative suspensions. Depending on the road roughness and the vehicle speed it may be possible to recover several hundred Watts from the suspension system using a controlled electrical machine. A prototype device is demonstrated with deviations from ideal behaviour found to be the result of nonlinear effects such as friction and backlash.

The paper of Swift, Smith and Glover deals with the performance of passive spring-damper mechanical networks in vehicle suspension systems, which can then be improved with the inclusion of a mass-like third component called the inerter. They propose a fluid-based inerter device that has advantages over mechanical ball-screw type devices in terms of design simplicity. This implementation is robust and durable and has the flexibility to be integrated into more general mechanical suspension networks.

Applying advanced control methods to challenging applications, and using applications to stimulate new research work was an essential part of Alistair's *modus operandi*. In their applications paper Yuan and Glover study the feedback stabilization of thermoacoustic instabilities in partially premixed lean combustion; self-excited oscillations are a particular problem in lean partially premixed combustion systems. The aim of this research is to suppress these oscillations using feedback and the purpose of the work presented is to investigate a model-based approach to the feedback control of this problem. A number of robust control design methods are employed to obtain a feedback controller and it is observed that the robustness to system uncertainty is significantly better for a low-complexity controller in spite of the use of similar design norms.

The work of Shaked and Allerhand continue the robustness theme, but consider instead robust estimation. In their work a covariance analysis is introduced for linear switched systems with dwell time constraints. This analysis reduces the conservatism that is encountered in the analysis of switched systems without dwell. An upper-bound on the covariance of the state vector is estimated for both nominal and uncertain switched system models. The results are applied to robust filtering problems in switched systems with driving and measurement noise signals, where filters of general type filters are considered. The paper also examines methods aiming to overcome the deficiencies of the standard approaches to robust filtering of systems with large parameter uncertainties and a new method of estimation for non-switched, exponentially stable, uncertain systems is developed.

Postlethwaite and Kothari develop a robust motion planner for autonomous vehicles flight paths. A multi-agent motion planner is developed for nonlinear Gaussian systems using a combination of probabilistic approaches and a rapidly-exploring random tree (RRT) algorithm. A closed-loop model consisting of a controller and estimation loops is used to predict future distributions to manage the level of uncertainty in the path planner. Probabilistic constraints are used to reduce the chance of constraint violations. Conflicts among agents are resolved using a prioritization scheme. The planner's effectiveness is demonstrated by example.

Closely allied to conventional optimal control is so called model predictive control. Model predictive control is closely related to problems such as linear-quadratic optimal control, preview control and fixed-lag smoothing all of which were strong interests of Alistair. David Mayne, a close contemporary of Alistair's, is a leading light in optimal control as well as model predictive control. Because model predictive control is essentially nonlinear in nature, even if the plant model is not, establishing closed-loop stability guarantees is not straight forward and usually involves the use of a terminal-cost constraint. David Mayne explains why these constraints are necessary and defends their use.

Continuing with the model-predictive control theme, Cheng, Cannon and Kouvaritakis seek to advance the design of robust MPC schemes and consider optimization schemes that are based on minimizing the nominal prediction cost. They introduce dynamics into the prediction structure of RMPC through the use of a Youla parameter provides extra degrees of freedom with which to desensitize the cost to model uncertainty and develop a methodology that allows this idea to be used in the presence of constraints. To avoid limitations concerning the systematic design of the Youla parameter, more general prediction dynamics are considered and an efficient control algorithm with guaranteed feasibility and stability is presented. A simple modification is also proposed that minimizes the worst case cost while retaining the same control theoretic properties and efficiency of implementation. The benefits of their algorithms are illustrated by numerical example.

The concluding paper by Hartley, Gallieria and Maciejowski introduces an aerospace application of model-predictive control story with a 1-norm regularisation term. The recently investigated LASSO model predictive control (MPC) is applied to the terminal phase of a spacecraft rendezvous and capture mission and the interaction between the cost function and the treatment of 'minimum impulse bit' is also investigated. It is shown that LASSO MPC meets tighter specifications on control precision, and also avoids the risk of undesirable behaviours often associated with pure 1-norm stage costs.

It is our pleasure to dedicate this special issue to Sir Alistair G.J. MacFarlane with respect and admiration. We would like to close this editorial with some personal reminiscences.

Nicos Karcanias first met Alistair Macfarlane in Manchester in October 1972. At the time he was a postgraduate attending the MSc course in UMIST on the Theory and Practice of Automatic Control, where both Alistair MacFarlane and Howard Rosenbrock were inspirational lecturers. He was accepted by MacFarlane for his MSc Dissertation, undertaken in the summer of 1973, to carry out an investigation on the *Geometric Theory of Phase in Multivariable Systems* using the Lanczos decomposition. At the time MacFarlane had a very strong interest in the use of singular values as means of assessing performance in multivariable systems and his report on this was used by a number of his research students at the time. That period in Manchester and in particular his interaction with Alistair was crucial for his further development. He was accepted by Alistair as a Doctoral student in October 1973 and followed him, together with Basil Kouvaritakis in Cambridge in August 1974. Alistair's arrival in Cambridge in 1974, changed the overall scene and direction of the

Control Group in Cambridge by putting the emphasis on Multivariable Control and making an effort to link Control with Operational Research. This led to the establishment of a larger group, the *Control and Management Systems Division*. This latter initiative was an expression of his vision of the need to migrate control concepts to a wider area of applications. The role of the Common Room in Mill Lane in the promotion and development of research and the weekly meetings of the Control Group are still fond memories from that period. The contributors to this special issue are research students and colleagues of Alistair from the Cambridge period.

David Limebeer has arrived in Cambridge in August 1980 to take up a post-doctoral research fellowship having just completed a PhD on the suppression of torsional instabilities in large turbo generator shaft systems. As with all his new students and post-docs Alistair immediately made me feel welcome and showed a genuine interest in my past work as well as in my personal welfare. While I had read a lot of MacFarlane's work prior to arriving in Cambridge, I do recall reading the paper: A. G. J. MacFarlane and D. F. A. Scott-Jones. *Vector gain*. International Journal of Control, 29(1):65–91, 1979 soon after my arrival. This paper anticipated some of the important ideas that were soon to be further developed under the robust control banner and is just another example of Alistair's vision and research leadership. Working in the Control Group in Mill Lane, while attempting to read the black board through clouds of Greek cigarette smoke, was a truly unforgettable experience!

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