



Abstracts and titles for IEEE Colloquium on Optimisation for Control

April 24th 2006 at the University of Sheffield

10.00-10.50 The Scenario Approach to Robust Control

Marco Campi

University of Brescia , IEEE Distinguished lecturer

Many worst-case robust control problems cannot be solved due to computational intractability.

In this talk, a new probabilistic solution framework is proposed for robust control analysis and synthesis problems that can be expressed in the form of robust convex optimization. This includes for instance the wide class of NP-hard control problems representable by means of parameter-dependent linear matrix inequalities (LMIs).

By appropriate sampling of the constraints, one obtains a convex optimization problem (the scenario problem) that can be easily solved through standard optimization techniques. The solution of the scenario problem is approximately feasible for the original (usually infinite) set of constraints, i.e. the measure of the set of original constraints that are violated by the scenario solution rapidly decreases to zero as the number of samples is increased. Explicit and efficient bounds on the number of samples required to attain a-priori specified levels of probabilistic guarantee of robustness are given.

A rich family of control problems which are in general hard to solve in a deterministically robust sense is therefore amenable to polynomial-time solution if robustness is intended in the proposed risk-adjusted sense.

10.50-11.20 Optimal UAV Flight Paths Selection

Da-Wei Gu

University of Leicester

Uninhabited Air Vehicles (UAV) are advantageous over piloted counterparts in terms of manoeuvrability, low human risk, low cost and light weight, and is an important development area in the aerospace industry for the 21st century. Wide use of UAVs for civil, military and commercial applications (including weather and atmospheric monitoring, emergency communications, telecommunications, border patrol, and battlefield deployment) demands UAVs with higher levels of autonomous behaviour. A basic issue of UAV autonomy is the flight path planning. Planning algorithms must compute a stealthy path which steers the vehicle away from potential dangers. The path selected should be optimal in a certain sense as well as practically feasible. The algorithm must be fast enough for real time use in an uncertain environment, and efficient in memory and computational demand so

that it can be run on airborne processors. The talk will introduce two path planning algorithms: an improved Voronoi graph method and a finite receding horizon method employing mixed integer linear programming (MILP) techniques. A battlefield scenario will be used to illustrate the application of the two approaches.

11.20-11.50 Global optimisation and search space pruning in spacecraft trajectory design

Victor M. Becerra

Reading University

Most interplanetary trajectory design problems can be stated as optimisation problems where the minimisation of fuel requirements is the fundamental goal, but also other criteria such as mission duration, time windows for launch and arrival, thrust and velocity constraints, are considered. Local optimisation and the minimum principle have often been employed for interplanetary trajectory design; however, due to the nonlinearities and the orbital nature of the solar system, most mission design problems exhibit many local minima. The use of global optimisation techniques is starting to have an impact on interplanetary trajectory design. However, difficulties arise due to the sheer size of the search space associated with these problems. Hence the need for pruning the search space in order to reduce computational complexity and time. The talk will describe an automated space pruning technique for multiple gravity assist problems which exhibits polynomial time and space complexity, and which typically achieves search space reductions of six orders of magnitude or more. Illustrative examples and a software demonstration will be given.

11.50-12.10 Modified Crossover Operator Approach for Evolutionary Optimization

Amr Madkour

University of Bradford

This research presents an investigation into a new population inheritance approach using a concept taken from the recessive trait idea for evolutionary optimization. Evolutionary human inheritance recessive trait idea is used to enhance the effectiveness of the traditional genetic algorithms (TGAs). The capability of the modified approach is explored by two examples *(i)* a mathematical function of two variables, and *(ii)* an active vibration control (AVC) of a flexible beam system. Finally, a comparative performance for convergence is presented and discussed to demonstrate the merits of the modified genetic algorithms (MGAs) approach over the traditional ones

12.10-12.30 Real-time Engineering Flight Simulator

David Allerton

University of Sheffield

ACSE has a real-time flight simulator which is used for the design and evaluation of future aircraft systems, including flight control systems, navigation and guidance systems, aircraft displays and flight safety. The simulator is based on an array of PCs coupled with thin-wire Ethernet and provides real-time (50 Hz) non-linear flight models of a range of civil and military aircraft. The simulator also includes advanced data capture and analysis software and an impressive 3D projection system. The demonstration will include an opportunity for 'hands-on' flying.

13.10-13.40 Sensitivity Analysis and Optimal Control

Richard Vinter

Imperial College London

Sensitivity analysis concerns the manner in which optimal controls and the minimum cost are affected, when parameters in the underlying system dynamics and cost function change. This talk centres on recent advances in the field and, in particular, the characterization of sensitivities in terms of Lagrange multipliers. Optimal control is widely used in the selection of nominal flight trajectories, for tracking purposes, in aerospace applications. We discuss the relevance of sensitivity analysis here. It is shown how it can be used to predict performance degradation caused by parameter drift and action of disturbances, and to mitigate its effects.

13.40-14.00 Optimisation Methods for Robustness Analysis: Aerospace and Biological Applications

Declan Bates

Leicester University

Robustness analysis is concerned with identifying and quantifying worst-case behaviour in complex uncertain systems. Such problems have traditionally been motivated by the need to guarantee acceptable levels of stability and performance in automatic control systems, especially in the case of safety-critical applications such as flight control laws. Recently, robustness analysis has also become a powerful tool with which to (in)validate mathematical models of biological systems which possess inherent robustness to changes (uncertainty) in their environment. In this talk, I describe how global optimisation methods can be used to overcome the computational complexity associated with certain robustness analysis problems. I will also demonstrate how the hybridisation of global optimisation algorithms with local gradient-based methods can deliver dramatic performance improvements, both in terms of reliability and computation times. Applications of the proposed approach to robustness analysis problems from the aerospace and systems biology fields will be presented.

14.00-14.30 Evolving Control Systems Engineering Design Solutions

Peter Fleming

University of Sheffield

Control engineering design problems can often be conveniently formulated as multiobjective optimisation problems and evolutionary computing algorithms have proven effective in their solution. Industrial application examples will illustrate this.

However, evolutionary multiobjective optimisation has traditionally concentrated on problems comprising 2 or 3 objectives and control design problems can often comprise a relatively large number of objectives. Such problems pose new challenges for algorithm design, visualisation and implementation. Progressive articulation of design preferences can be used to assist in reducing the region of interest for the search and, thereby, simplify the problem. Parallel coordinates have proved a useful tool for visualising many objectives in a 2-D graph and the computational grid and wireless PDAs offer technological solutions to implementation difficulties arising in complex system design.

14.30-14.50 Multi-objective Controller Design: Evolutionary Algorithms and Bilinear Matrix Inequalities for a Passive Suspension

*A. Molina-Cristóbal, C. Papageorgiou, G. T. Parks, M. C. Smith, P. J. Clarkson
University of Cambridge*

The main aim of this talk is to discuss multi-objective controller design. We will first introduce current multi-objective controller design approaches using convex optimisation via linear matrix inequalities (LMIs). We will then turn our attention to two multi-objective optimisation techniques for the design of a passive suspension for a quarter-car vehicle model. These techniques are based on meta-heuristic optimisation and bilinear matrix inequalities (BMIs) respectively. The use of the BMI technique was motivated by the fact that both the performance measures and the passive nature of the suspension can be formulated using matrix inequalities. The characterisation of a positive real passivity constraint using matrix inequalities and the use of a new mechanical element, the inerter, permit optimisation over the entire class of positive real admittances and the realisation of the resulting admittance using passive elements. The meta-heuristic optimisation is based on evolutionary algorithms (EAs) and it has proved more favourable than the BMI technique from a computational point of view, although both techniques give similar results.

15.00-15.20 Dynamic Optimisation and Automatic Differentiation

*Yi Cao
Cranfield University*

Dynamic optimisation is widely application in many control and control related areas, such as model predictive control, adaptive control, robust control, system identification and state estimation. Fundamentals of dynamic optimisation, also known as optimal control theory have been known at least for 50 years. However, few real problems can be analytically solved using these fundamentals. Most practical problems have to rely on numerical techniques. In spite of the rapidly increased computing power and availability of sophisticated nonlinear optimisation software, there are still many unsolved issues relating to dynamic optimisation algorithms, particularly for continuous time systems. These issues include efficiency, accuracy and local optimality. In this talk, automatic differentiation techniques are applied to solve continuous time dynamic optimisation problems. The advantages and limitations of the new approach are discussed and demonstrated via examples.

15.20-15.40 Analysis Work Carried Out On Control Systems When A Negative Acceleration Feedback Term Is Applied, And How The Analysis Conflicts With Existing s-Plane “Standard Form” Theory.

Fred Garner

Research was carried out by the author regarding the performance and optimisation of rate-gyroscope stabilisation systems for the control of load inertias when the carrier vehicle is subjected to 3-axis angular disturbances. A substantial laboratory test rig was constructed (25 kw peak), Matlab / Simulink system models were generated, and symbolic transfer function expressions were derived and analysed.

In order to obtain the desired Nichols plots for numeric versions of the symbolic transfer functions, for Matlab / Simulink models, and for the test rig itself, it was always necessary to use a negative-acceleration feedback term in the form of a minor feedback loop. This technique has been used in control systems for many years, but the writer considered that the need to apply this particular feedback method had not been analysed adequately, and was not understood sufficiently well.

As a completely separate exercise from the rate-gyroscope analysis work, it was decided to investigate the topic. Transfer functions were generated for a wide range of control systems, containing from one to three identifiable inertias and from one to four resilience elements, the systems being driven by a brushless servo motor and a motor controller unit. Transfer functions were analysed using Mathematica software and equivalent system models were generated using Matlab / Simulink.

Adjustable negative-acceleration feedback terms were derived using three methods.

1. Using the output from a motor-tacho, differentiated to produce a motor acceleration term.
2. Using the output from a load-inertia tacho, also differentiated to produce a load acceleration term.
3. Using motor current feedback.

The effects of the three methods are quite different, and have been analysed thoroughly.

For some years, the author had also considered that “Standard form” transfer function expressions, first postulated by A. L. Whiteley (D.Sc. Leeds. 1945) are not feasible, and never had been, and that the form of the equations presented in both textbooks and learned papers is incorrect. These points were referred to in papers published by the writer in 2003 and 2005. The analysis has allowed the correct form of such expressions to be verified, and a set of rules, governing the form and order-in-s of numerator and denominator expressions, has been derived.

The analysis compared results from Mathematica, derived using more than one analysis method, with results from corresponding Matlab / Simulink models. One significant conclusion from the analysis is that “Standard form” expressions are incorrect in principle and are not possible to achieve in practice. The requirement for, and the effect of, a negative-acceleration feedback term, has been established. The analysis work has taken some two and a half years and is now effectively complete, but the work and conclusions have not yet been published.

15.40-16.00 Optimal hardware and control system design for aero and auto applications

Paul Stewart

University of Sheffield