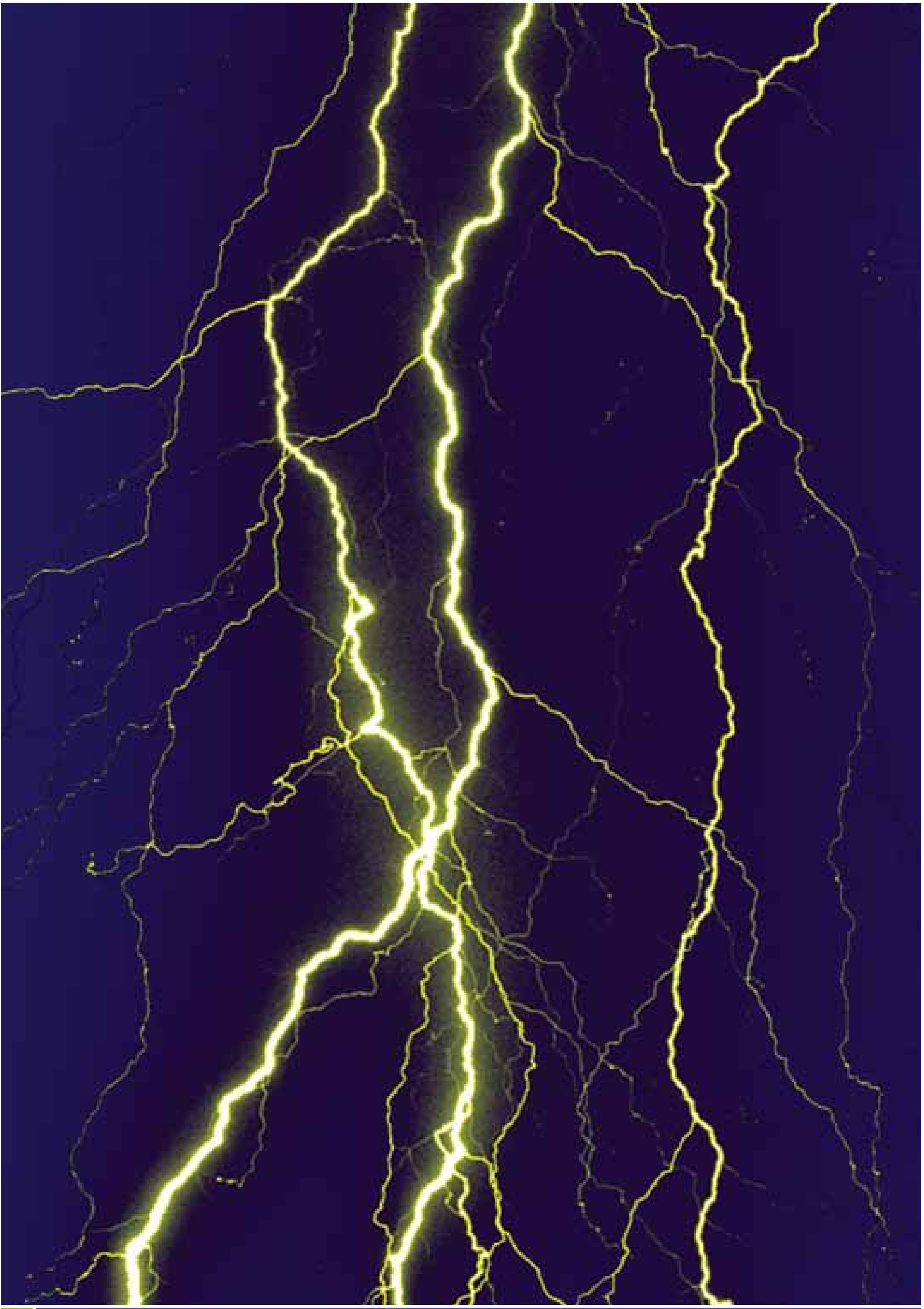

ANNUAL REPORT

ARC Centre for Complex Dynamic Systems and Control

2005

CDSC

The University of Newcastle Australia

Enquiries and Further Information

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Table of Contents

Our Vision

To be a world leader in analysis, design and optimisation of complex dynamic systems; pursuing outstanding fundamental and applied research.

Director's Report

2005 has been a time of excellent progress building on the solid base that has been established in previous years. Our research programs and staff are now firmly established, and generating a range of research results as can be seen in our report. There are a number of things in our Highlights section that I commend to your attention. One particular thing I would like to note here is the State Government support (courtesy of the NSW Department of State and Regional Development) for CDSC secured during 2005. This will be devoted to supporting research projects in NSW with a particular emphasis on building up the industrial projects we have with local industries.

It has also been very heartening to see the success of several researchers associated with CDESC in attracting grants for projects that complement Centre activities.

We are sorry to see that Richard Gerlach has left the University of Newcastle, to take up a Senior Lectureship at the University of NSW, and we wish him well in his new position. We have welcomed new staff Sumeet Aphale, Mina Kardani, David Allingham, MeiMei Zhang.

On a personal note, I owe a great deal of thanks to Graham Goodwin, Dianne Piefke and others for all their work done in my absence. I have been able to focus on some new research initiatives whilst on sabbatical leave at the Hamilton Institute, Maynooth, Ireland during the second half of 2005. This has been a great opportunity to learn some new things in Systems Biology and Dynamics of Communication Networks which relate well to the Centre's work. I look forward to further developments in these and other areas in the coming years.

R. H. Middleton

Rick Middleton
Director

Staff

Director
Professor Richard H. Middleton

Research Director
Professor Graham C. Goodwin

Program Leaders
Professor Minyue Fu – Signal Processing
Dr. Richard Gerlach (UN) – Bayesian Learning
Professor Graham Goodwin – Control System Design
Professor Kerrie Mengersen (QUT) – Bayesian Learning
Professor Richard Middleton– Process Control and Optimization
Associate Professor Reza Moheimani – Mechatronics
Professor Iain Raeburn – Mathematical Systems Theory

Chief Investigators
Dr. Julio Braslavsky
Dr. Jose De Doná
Dr. Richard Gerlach
Dr. Maria Seron
Associate Professor Brailey Sims

Industry Partner Investigators
Dr. Salvatore (Sam) Crisafulli (Matrikon)
Dr. Merab Menabde (BHP-Billiton Innovation)
Mr. Chris Shelton (BHP-Billiton Innovation)
Mr. Peter M. Stone (BHP-Billiton Innovation)
Mr. Richard Thomas (Matrikon)
Mr. Tom Honeyands (BHP-Billiton Innovation)

Associated Investigators
Dr. Robert King
Dr. Darfiana Nur
Dr. David Pask
Dr. Jacqui Ramagge
Mr. Paul Rippon
Dr. Wojciech Szymanski
Dr. James Welsh

Academic Research Staff
Dr. Greg. Adams
Dr. David Allingham
Dr. Sumeet Aphale
Dr. Andrew Fleming
Dr. Zahirul Hoque
Dr. Katrina Lau
Dr. Ross McVinish (QUT)
Dr. Kaushik Mahata
Dr. Claus Müller
Dr. Aidan Sims
Dr. Ian Wood (QUT)
Dr. Trent Yeend
Dr. Mei Mei Zhang

Engineering Staff
Mr. Adrian Bastiani
Ms. Fatima Kardani
Mr. Frank Sobora
Mr. Michael Santarelli

Support Staff
Mrs Dianne Piefke – Executive Officer
Mrs Jayne Disney – Administrative Assistant

Postgraduate Research Students

Juan Carlos Aguero (Thesis Accepted)
"Novel algorithms on system identification"
Supervisor: G.C. Goodwin
Co-Supervisor: J.A. De Doná
Degree: PhD

Stephen Allen
"Corners in graph algebra"
Supervisor: D. Pask
Co-Supervisor: I. Raeburn
Degree: PhD

Clair Alston
"Mixture models"
Supervisor: K. Mengersen
Degree: PhD

Sam Behrens (Graduated 2005)
"Self-sensing piezoelectric actuators"
Supervisor: S.O.R. Moheimani
Co-Supervisor: G.C. Goodwin
Degree: PhD

Milan Derpich (Commenced 2005)
"Sampling and quantization in audio compression"
Supervisor: G.C. Goodwin
Degree: ME

Petra Graham (Graduated 2005)
"Statistical methods for quality in hospitals"
Supervisor: K. Mengersen
Degree: PhD

Boris Godoy
"Modelling and control of copper leaching processes"
Supervisor: J.H. Braslavsky
Co-Supervisor: R.H. Middleton
Degree: ME

Hernan Haimovich
"Quantisation issues in feedback control"
Supervisor: G.C. Goodwin
Co-Supervisor: M.M. Seron
Degree: PhD

Bryan Hennessy
"Stochastic optimal control applied to mine planning"
Supervisor: G.C. Goodwin
Co-Supervisor: M.M. Seron
Degree: ME

Kate Lee – QUT (Commenced 2005)
"MCMC algorithms"
Supervisor: K. Mengersen
Co-Supervisor: R. McVinish
Degree: PhD

Christian Lovaas (Commenced 2005)
"Robust model predictive control"
Supervisor: G.C. Goodwin
Co-Supervisor: M.M. Seron
Degree: ME

Iskandar Mahmoud (Commenced 2005)
"System identification and robust control of spatially distributed systems"
Supervisor: S.O.R. Moheimani
Co-Supervisor: B.M. Ninness
Degree: ME

Jose Mare
"Dynamic programming solution to model predictive control"
Supervisor: J.A. De Doná
Co-Supervisor: G.C. Goodwin
Degree: ME

Adrian Medioli
"Nonlinear model predictive control"
Supervisor: R.H. Middleton
Co-Supervisor: M.M. Seron
Degree: PhD

Trevor Moffiet
"Statistical methods for software and decision report for remote sensing analysis"
Supervisor: K. Mengersen
Co-Supervisor: R. King
Degree: PhD

Timothy Moore
"Applications of statistics to robot soccer"
Supervisor: S. Chalup
Co-Supervisors: R.H. Middleton/R. King
Degree: ME

Zead Mustafa (Graduated 2005)
"A new structure for generalized metric spaces with applications to metric fixed point theory"
Supervisor: B. Sims
Co-Supervisor: G. Willis
Degree: PhD

Jun Ning (Graduated 2005)
"Serially concatenated codes for continuous phase modulation"
Supervisor: M. Fu
Degree: PhD

Daniel Quevedo (Thesis Accepted)
"Quantized moving horizon optimization"
Supervisor: G.C. Goodwin
Co-Supervisor: J.A. De Doná
Degree: PhD

Marcel Ratnam
"Robust control of nano-positioning systems"
Supervisor: S.O.R. Moheimani
Co-Supervisor: R.H. Middleton
Degree: PhD

Paul Rippon
"Statistical process control"
Supervisor: K. Mengersen
Co-Supervisor: R. King
Degree: PhD

Alejandro Rojas
"Control over signal to noise ratio limited channels"
Supervisor: R.H. Middleton
Co-Supervisor: J.H. Braslavsky
Degree: PhD

Osvaldo Rojas (Graduated 2005)
"A frequency domain approach to constrained receding horizon control"
Supervisor: G.C. Goodwin
Co-Supervisor: R.H. Middleton
Degree: PhD

Elizabeth Stojanovski (Thesis submitted)
"Multivariate methods in the health sciences"
Supervisor: K. Mengersen
Degree: PhD

Arief Syaichu-Rohman (Graduated 2005)
"Optimisation based feedback control of input constrained linear systems"
Supervisor: R.H. Middleton
Degree: PhD

Ian Searston
"Analysis in geodesic metric spaces"
Supervisor: B. Sims
Co-Supervisor: G. Willis
Degree: PhD

Mark Smith
"Ultramethods in metric fixed point theory"
Supervisor: B. Sims
Co-Supervisor: G. Willis
Degree: PhD

Frank Tuyl
"Confidence intervals for binary data"
Supervisor: R. Gerlach
Co-Supervisor: K. Mengersen
Degree: PhD

Jason Tyler
"Topics in graph algebras"
Supervisor: I. Raeburn
Co-Supervisor: W. Szymanski
Degree: PhD

Ben Vautier (Graduated 2005)
"Charge driven piezoelectric actuators for structure vibration control: Issues and implementation"
Supervisor: S.O.R. Moheimani
Co-Supervisor: S.R. Weller
Degree: ME

Wang Meng
"Impact of uncertainty on MIMO communication systems"
Supervisor: G.C. Goodwin
Co-Supervisor: R.H. Middleton
Degree: ME

Darren Wraith (QUT)
"Bayesian multivariate risk assessment in environmental health"
Supervisor: K. Mengersen
Co-Supervisor: S. Tong
Degree: PhD

Trent Yeend (Graduated 2005)
"Topological higher-rank graphs, their groupoids and operator algebras"
Supervisor: I. Raeburn
Co-Supervisor: D. Pask
Degree: PhD

Juan Yuz (Thesis Accepted)
"Sampling issues in estimation and control"
Supervisor: G.C. Goodwin
Degree: PhD

Zhuo, Xiang Wei
"Connections between constrained control and estimation"
Supervisor: J.A. De Doná
Degree: ME

Advisory Board

The Advisory Board met in Newcastle on Friday 8 April 2005 to offer advice on matters of concern to the Centre. The current membership of the Advisory Board is:

Professor B.D.O. Anderson
NICTA, and Research School of Information Science and Engineering, Australian National University, Canberra, ACT.

Professor A. Carey
Mathematical Sciences, Australian National University. Canberra, ACT.

Dr. S. Crisafulli
Matrikon, Mayfield, NSW.

Dr. W.J. Edwards
Industrial Automation Services Pty. Ltd., Teralba, NSW.

Mr. R. Hayes
Shell Refining (Australia) Pty. Ltd., Clyde Refinery, Rosehill, NSW.

Professor W. Hogarth
Pro. Vice-Chancellor, Faculty of Science and Information Technology, The University of Newcastle, Callaghan, NSW.

Professor R. Jarvis
Monash University, Melbourne, Victoria.

Professor R.J. Macdonald
Deputy Vice Chancellor (Research), The University of Newcastle, Callaghan, NSW.

Professor I.M.Y. Mareels
Melbourne University, Melbourne, Victoria.

Professor A.W. Page
Pro. Vice-Chancellor, Faculty of Engineering and Built Environment, The University of Newcastle, Callaghan, NSW.

Mr. R. Peirce
Technical Systems, CSR Victoria Mill, Ingham, Queensland.

Chief Executive Officer
TUNRA Limited, Callaghan, NSW.

Dr. E.H. Van Leeuwen
Exploration and Development, BHP Billiton Innovation, Melbourne, Vic.

Professor I.R. Petersen
Australian Defence Force Academy, UNSW, Canberra, ACT.

Visitors

Professor Arie Feuer
Department of Electrical Engineering, Technion-Israel Institute of Technology, Haifa, Israel: August – October

Mr. Ulrik Hald (student)
Department of Control Engineering, Aalborg Universitet, Denmark: July – December

Dr Piotr Hajac
Faculty of Physics, Warsaw University, Krakow, Poland: August

Dr Jeong Hee Hong
Department of Applied Mathematics, Korea Maritime University, Busan, Korea: January – February

Dr. Ernesto Kofman
Department of Electronic Engineering, National University of Rosario, Argentina: April – May

Professor Alex Kumjian
Department of Mathematics, University of Nevada at Reno, USA: July – August

Dr John Jairo Martinez Molina
Laboratory of Automatic Control of Grenoble, ENSIEG, France: April – May

Professor Daniel Miller
Department of Electrical Engineering, University of Waterloo, Canada: January – May

Professor Osvaldo Rosso
Ciudad Universitaria, Argentina: March – April

Professor Ryszard Nest
Department of Mathematics, University of Copenhagen, Denmark: August

Professor Christian Skau
Department of Mathematics, Norwegian University of Science and Technology, Trondheim, Norway: November – December

Mr. Lars Ventergaard (student)
Department of Control Engineering, Aalborg Universitet, Denmark: July – December

Professor Robert Wolpert
Institute of Statistics and Decision Sciences, Duke University, USA: September

Professor Yoo, Kyung Sang
Department of Electrical Engineering, Doowan Technical College, Korea: January 2004 – January 2005

Seminars

Research students and staff from the Centre and the University of Newcastle as well as Australian and international visitors participate in the Centre's seminar series. Seminars presented in 2005 are listed below.

1 February

Mr. Alejandro Rojas

CDSC, The University of Newcastle

"Output feedback stabilisation over bandwidth limited, signal to noise ratio constrained communication channels"

14 February

Mr. André Cuppen

University of Technology, Eindhoven, The Netherlands

"Linear induction machine with homogeneous mild steel secondary in generation mode"

2 March

Dr. David Allingham,

CDSC, The University of Newcastle

"A computational Cochlear implant model: Signal through noise"

6 April

Mr. Wei Zhuo Xiang

CDSC, The University of Newcastle

"Relationships between constrained control and constrained estimation problems"

13 April

Professor Daniel Miller

Department of Electrical and Computer Engineering, University of Waterloo, Canada

"Stabilization in the presence of an uncertain arbitrarily large delay"

18 April

Dr. Ernesto Kofman

Laboratory for System Dynamics and Signal Processing

School of Electronic Engineering, FCEIA,

National University of Rosario, Argentina

"Quantization tools for ODE discretization and control"

18 May

Dr. John-Jairo Martinez

Laboratoire d'Automatique de Grenoble

Institut National Polytechnique de Grenoble, France.

"Model reference control approach for safe longitudinal control"

15 June

Dr. Richard Gerlach

Statistics, School of Mathematical and Physical Sciences, The University of Newcastle

"MCMC methods for model selection and estimation in threshold nonlinear heteroscedastic models"

27 July

Mr. Adrian Medioli

CDSC, The University of Newcastle

"Constraints, Stability and Feasibility Issues in MPC"

24 August

Professor Arie Feuer

Department of Electrical Engineering, Techniuon – Iasrael Institute of Technology, Israel

"Compression at the source – transforming a home digital camcorder into ahd"

Conferences, Courses and Workshops

Professor Wolpert (third from the left) with QUT Research Fellows Sama Low Choy, Grant Hamilton and Clair Alston

Professor Aitkin leading a case study at the workshop

Jose De Dona presenting Constrained Estimation and Control Short Course in Argentina

The 2nd annual international meeting, "Bayesian Topics in the Tropics", was organised as a Program activity, in collaboration with the Statistical Society of Australia and the Australasian Society for Bayesian Analysis. The meeting was held on Stradbroke Island and was attended by about 40 people from four countries. Professor Robert Wolpert, (Duke University USA) and Murray Aitkin (Professorial Fellow, University of Melbourne) were the two keynote speakers. In addition to attending the workshop, Professor Wolpert spent two weeks with Program researchers at QUT.

Kerrie Mengersen is Program Chair for the Joint World Valencia/ ISBA Meetings, Valencia, June 2006 and is a member of the Program Committee for the Australian and New Zealand Statistics Conference in Auckland, July 2006. She also organised two sessions on Bayesian statistics at the MODSIM conference in Melbourne, December 2005.

A two-day short course, "Bayes for Beginners", was delivered by Program Leader Mengersen in Adelaide, at the invitation of the Statistical Society of Australia. The course was attended by 40 people from various academic, government and industry organisations.

A short course on "Constrained Estimation and Control" was presented by Seron, Goodwin and De Doná to postgraduate students and industry in February 2005. This course was also presented 26-30 September at Universidad Nacional del Comanue, Neuqueén, Argentina by Jose De Doná. The course was attended by participants from the research groups of 4 different universities.

Graham Goodwin participated in a Workshop organised by Rick Middleton and other international researchers on "New Developments in Control Performance Limitation Research: A Tale in the Network Age" at the joint Conference on Decision and Control and European Control Conference, Sevilla, Spain in December.

Rick Middleton is Program Chair for the 2006 IEEE Conference on Decision and Control, to be held in San Diego, December, 2006.

Selected Highlights 2005

Professor Graham Goodwin was awarded the Harold Chestnut Control Engineering Text Book Prize

Postgraduate Systems and Control Workshop was held in Melbourne 14-15 February. Seven postgrad students and two academic staff attended from Newcastle.

We are delighted to report that eight researchers associated with CDSC (A. Fleming, M. Fu, G. Goodwin, K. Mengersen, R. Moheimani, D. Pask, A. Sims and J. Welsh) were successful in obtaining highly competitive ARC Discovery funding for new projects commencing in 2006. These projects complement CDSC activities, and are an indication of the excellent researchers involved with the Centre.

The Centre Annual retreat was held on 7 October at Bayview's Function Centre, Warners Bay. Each programme was outlined in oral presentations after which postgraduate students displayed posters of their work. Participants included Centre staff, students and representatives from industry partners, as well as overseas visitors to the Centre.

In July, the NUbots completed in the World Robocup Soccer, Sony 4 Legged League. They achieved 2nd place in a tough competition won by the German team, and also achieved 2nd place in the Technical Challenges component of Robocup.

Graham Goodwin was awarded Fellow of IFAC at World congress in Prague, (July 4-8).

Professor Graham Goodwin was awarded the Harold Chestnut Control Engineering Text Book Prize from IFAC for the book: G.C. Goodwin, S.F. Graebe, M.E. Salgado, "Control System Design", Prentice Hall, 2001.

Professor Graham Goodwin served as a Director of National ICT Australia until June 2005.

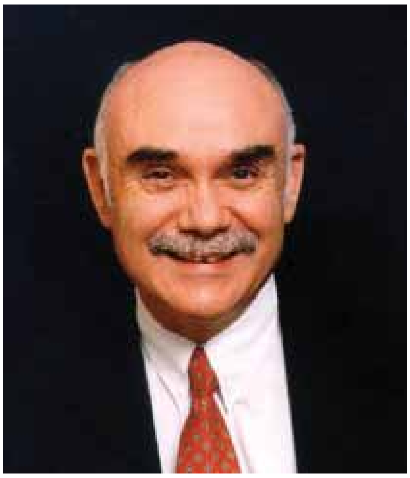
Kerrie Mengersen was elected Fellow of the Institute of Mathematical Statistics.

Kerrie Mengersen was elected Managing Editor of the Australian and New Zealand Journal of Statistics.

Rick Middleton was elected as Vice President – Conference Activities of the IEEE Control Systems Society for 2006 – 2007.

Research Programs

A. Control System Design



Graham Goodwin Program Leader

Maria Seron Deputy Program Leader

Program Goals

Control System design is a mature discipline. Surprisingly, however, the existing methodologies tend to be limited to relative standard problems – e.g. linear, unconstrained and with centralized architectures. As soon as one departs from these settings severe difficulties are faced.

Unfortunately many real world problems fall into these, so called, "complex" problems. These problems include such features as nonlinear and non-smooth behaviour, high state dimension and lack of convexity. This Program is aimed at addressing these issues using alternative theoretical tools and in the context of modern computational methods.

A.1 Fast Algorithms for Constrained Control

Researchers: Graham Goodwin, Maria Seron, Juan Yuz (Student), Christian Lovaas (Student)

In ongoing work, we have been concerned with the problem of developing fast algorithms for constrained control aimed at high dimensional systems possibly with fast sampling rates. In particular, we have developed fast algorithms which exploit an SVD decomposition of the Hessian associated with the problem.

A.2 Limiting Results in Constrained Control

Researchers: Graham Goodwin, Juan Yuz (Student), Arie Feuer (The Technion, Israel)

We have studied the problem of control of constrained linear systems when fast sampling rates are utilized. We have shown that there exists a well defined limit as the sampling rate increases. An immediate consequence of this result is the existence of a finite sampling period such that the achieved performance is arbitrarily close to the limiting performance. These results give further insight into the problem of constrained control. In particular they show that there exists a finite sampling rate such that the effect of discretization plays no significant role in the achieved performance.

In related work we have studied the asymptotic properties of the Hessian in discrete-time linear quadratic optimal control. We have shown that the singular values of the Hessian converge, in a well defined sense, to the principal gains in the frequency domain of an associated normalized system transfer function. We have treated the stable and unstable case for multi-input multi-output linear systems. Potential applications of the ideas include fast and/or robust algorithms for constrained model predictive control of discrete-time linear systems.

A.3 Generalised Hold Functions for Fast Sampling Rates

Researchers: Graham Goodwin, Juan Yuz (Student), Hugues Garnier (Université Henri Poincaré, France).

It is well known that the generalized hold functions can be used to mask nonminimum phase behaviour for continuous time systems in the sampled response. However, usually, this is associated with robustness problems.

We have considered the use of generalized holds to deal with sampling zeros only. We have proposed a hold design that places the sampling zeros asymptotically to the origin, when the sampling period tends to zero. The resulting generalized hold is only a function of the process relative degree. We have also investigated the robustness of the procedure with respect to both finite sample periods and unmodelled plant dynamics.

A.4 Performance Limitations Arising from Decentralised Architectures in Control

Researchers: Graham Goodwin, Mario Salgado (Universidad Técnica Federico Santa Maria, Chile), Eduardo Silva (Universidad Técnica Federico Santa Maria, Chile).

This project was described in the 2004 Annual report. A brief outline follows:

Control theory predominantly, deals with centralized (unrestricted) architectures. However, in practice, decentralized architectures are often preferred. The reasons for this preference are manifold and include ease of understanding, maintainability, cabling issues and others. In this research, our goal has been to gain insight into the fundamental performance limitations that arise from the use of a decentralized architecture. These fundamental limitations can guide the design of decentralized controllers and offer insight into the performance loss incurred by the use of a restricted architecture. An interesting feature of the results is that they depend, inter-alia, on the relative gain array (RGA). This gives new insight into this standard tool for assessing input-output pairings in decentralized control architectures.

A.5 Fundamental Constraints in Control Over SNR Limited Channels

Researchers: Rick Middleton, Julio Braslavsky, Jim Freudenberg (University of Michigan, USA), Alejandro Rojas (Student).

This project builds on work described in our 2003 and 2004 reports. The scenario under study is the problem of stabilisation of an unstable linear time invariant (LTI) plant by feedback over a communication channel. The approach pursued is based on the modelling of the channel as an additive white Gaussian noise (AWGN) channel with a constraint in the input signal to noise ratio (SNR). In contrast to other approaches in the literature, which are based on the use of quantisers and elaborate nonlinear coding and decoding schemes, the proposed approach yields a completely linear formulation to the stabilisation problem, enabling the application of a powerful existing theory for design and analysis of performance and robustness properties.

Progress in this project during 2005 included the extension of our results to channels with bandwidth constraints. New closed-form expressions have been obtained for the lowest bound in SNR required to achieve closed-loop stability over AWGN channels by LTI control for unstable, nonminimum phase plants with time delays. These bounds show that nonminimum phase zeros and time delays impose additional requirements in SNR to achieve stability with a LTI controller. Expressions for the controllers that achieve stability under the lowest SNR requirements have also been derived.

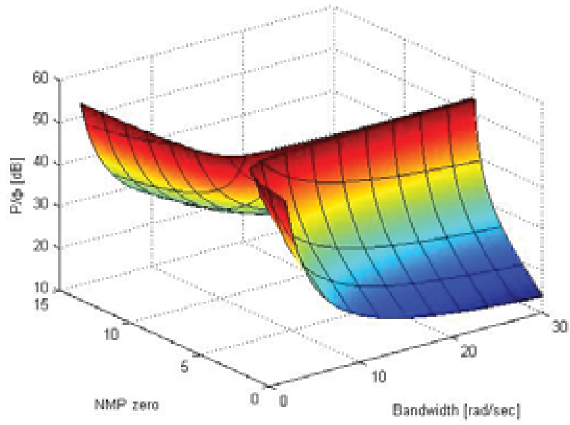


Figure 1: Bound on SNR required for stabilisability. Unstable pole at 5, NMP zero between 0 and 15. AWGN channel with limited bandwidth

On a different line of extensions, preliminary work has been done on the problem of achieving closed-loop stability and performance by LTI feedback over channels with additive white or coloured Gaussian noise. Linear quadratic Gaussian optimal control theory has been used to reformulate previous results in a unified framework, which allows the consideration of performance design specifications to the analysis of SNR constraints. When performance requirements are incorporated, the results have interpretations in terms of classical Wiener filtering concepts.

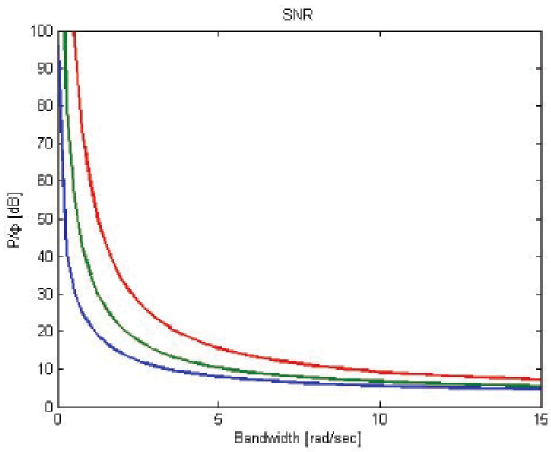


Figure 2: Bound on SNR required for stabilisability for the case of Butterworth filters of order 2 (blue line), order 5 (green line) and order 10 (red line).

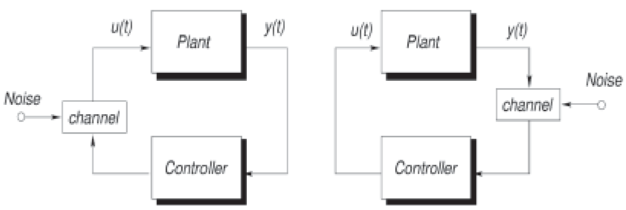


Figure 3: Schemes for LQG control over SNR constrained channels by loop transfer recovery at the input (left) and at the output (right).

A.6 Duality of Constrained Control and Estimation

Researchers: Graham Goodwin, Jose De Doná, Claus Müller, Maria Seron, Xiang Wei Zhuo (Student)

This project was described in detail in our 2003 and 2004 reports, and associated paper has now appeared. In particular, we have shown that the Lagrangian dual of a constrained linear estimation problem is a particular nonlinear optimal control problem. The result has an elegant symmetry, which is revealed when the constrained estimation problem is expressed as an equivalent nonlinear optimization problem. The results extend and enhance known connections between the linear quadratic regulator and linear quadratic state estimation problems.

The initial work dealt with constraints on process disturbances in estimation. However, in follow up work, Jose De Doná, Wei Zhou and Claus Müller have extended the result to cover measurement noise constraints.

A.7 Virtual Laboratories for Control System Design

Researchers: Graham Goodwin, Adrian Bastiani, Frank Sobora, Michael Santarelli, Peter Wellstead (Hamilton Institute, Maynooth, Ireland), Osvaldo Rojas (University of NSW, Sydney)

This project has been on-going for several years. We have now essentially completed the first phase of the project and hope to publish a book containing the first 12 Virtual laboratories in early 2006.

The current set of laboratories are:

Standard Laboratory Scale Experiments

Laboratory I – Electromechanical Servomechanism

Laboratory II – Coupled Tanks

Experiments Based on Industrial Scale Problems

Laboratory III – Centre Line Thickness Control in Rolling Mills I (Modelling and Classical Control)

Laboratory IV – Centre Line Thickness Control in Rolling Mills II (Periodic Disturbances and Observer Design)

Laboratory V – Continuous Casting Machine I (Linear Control)

Laboratory VI – Continuous Casting Machine II (Nonlinear Issues)

Laboratory VII – Rocket Dynamics

Laboratory VIII – Rocket Control

Laboratory IX – Cross Directional Control of Web Forming Processes I (Linear Design)

Laboratory X – Cross Directional Control of Web Forming Processes II (Accounting for Actuator Constraints)

Laboratory XI – Quantization of Music I (Effect of Noise Shaping Feedback)

Laboratory XII – Quantization of Music II (Bode Sensitivity Integrals)

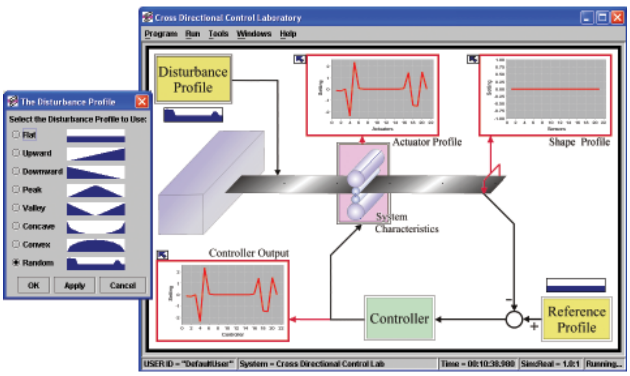


Figure 4: Cross Directional Control Laboratory

A.8 Geometric Framework for Quantised Control Systems

Researchers: Maria Seron, Graham Goodwin, Hernan Haimovich (Student)

This project deals with quadratic stabilisation of discrete-time systems with quantisers. In the 2004 Annual Report we described a geometric framework for the analysis and design of quadratically stabilising quantisers, especially aimed at providing more intuitive insight into minimum-density quantisers. The framework is based on analysing the partition induced on the state-space by a quantiser. This has allowed us to derive new results on minimum quantisation density for single-input systems, as well as to rederive well-known results from a different standpoint.

We have now extended this geometric framework to deal with multiple-input systems. Specifically, we have obtained an explicit geometric characterization of quadratically stabilising state feedback laws that are based on the use of multivariable quantisers of minimum dimension. This characterisation consists of a set of necessary and sufficient conditions for a quantised static state feedback to render a given quadratic function to be a Lyapunov function for the closed-loop system. These necessary and sufficient conditions are derived via explicit geometric considerations. The geometric characterisation developed provides a means to analyse and design quadratically stabilising quantised feedback laws. In particular, we have employed this characterisation in the design of multivariable quantisers having finite quantisation density for multiple-input systems with an arbitrary number of inputs.

A.9 Backlash Compensation

Researchers: Graham Goodwin, Yoo, Kyung Sang (Doowan Tech., Korea), Maria Seron

In this work we have investigated the use of receding horizon control for compensation of backlash at the input of a stable linear systems under control rate constraints. The problem was posed as a receding horizon optimal control problem by modeling backlash as a piecewise affine system with a state space partition consisting of three regions. This optimal control problem involves solving, at each step, 3N quadratic programmes, where N is the optimization horizon. As an alternative to solving the quadratic programmes, we have also proposed a strategy based on a suboptimal receding horizon control algorithm which utilizes a singular value decomposition of the Hessian of the quadratic programme (See project A.1). This alternative strategy leads, at the cost of some performance degradation, to much smaller computational load since a feasible rather than optimal solution has to be obtained at each step.

A.10 Robustness of Model Predictive Control

Researchers: Maria Seron, Graham Goodwin, Christian Lovass (Student), David Mayne (Imperial College, UK)

This project considers model predictive control (MPC) of linear, discrete-time systems with disturbances. We have obtained a novel result linking MPC and min-max optimal control theory. A distinction from previous work is that we show that typical MPC policies, which use the current system state, are the min-max optimal closed-loop policy with respect to a certain class of cost functions.

Specifically, we have shown, using min-max dynamic programming, that some of the existing approaches that are based on a restricted set of control policies and open-loop criteria, can, in fact, be seen as the solutions to min-max closed-loop optimal control problems albeit with different cost functions. Furthermore, the min-max cost function is "meaningful" in the sense that it puts positive definite quadratic weight on both the system state and the control input. The result provides a new interpretation of conventional MPC, and motivates the use of non-standard cost functions as a tool for enhancing the properties of associated min-max optimal control problems.

A.11 Fundamental Limits on the Achievable Delay Margin Using LTI Control

Researchers: Rick Middleton, Daniel Miller (University of Waterloo, Canada)

Time delay elements have long been known to be problematic in feedback systems, frequently giving rise to lightly damped oscillations or instability. The ability of a system to retain stability in the presence of an unknown time delay can be quantified by the 'Delay Margin' of a feedback system. It has recently been shown that by using linear time varying control, that in principle, an arbitrarily large gain margin is achievable when considering the control of a linear plant. However, until recently, it has remained as an open conjecture that with linear time invariant (LTI) control, for unstable plants, there is a limit to the achievable delay margin. We have recently been able to prove a number of results in this area, and, in particular, show that a linear time invariant plant admits an arbitrarily large delay margin using linear time invariant control if and only if all plant poles are either in the open left half plane, or at the origin of the complex plane. We have further been able to generate for a number of cases, upper bounds on the achievable delay margin using LTI control, and in some cases, we are able to prove that these bounds are in fact tight. Examples based on this work have highlighted some practical difficulties with the schemes that give optimal delay margin, however, the results still help verify the limits to the achievable performance in this case.

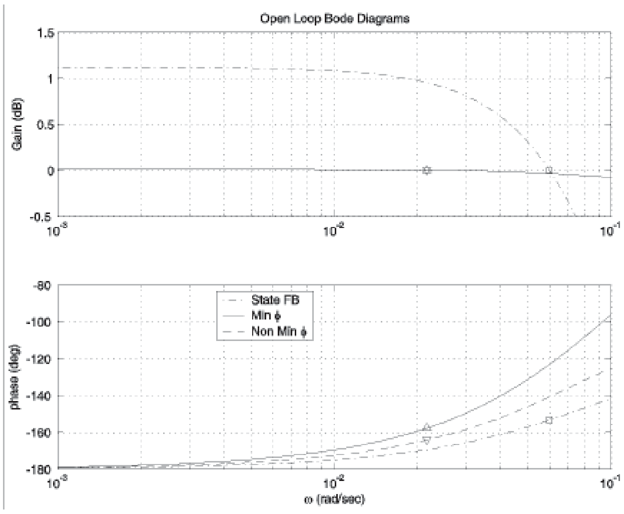


Figure 5: Bode diagrams illustrating some near optimal delay-margin control loops.

A.12 Fundamental Limits in Path Tracking

Researchers: Rick Middleton, Daniel Miller (University of Waterloo, Canada)

Traditionally, tracking control problems have been expressed as either Model Reference Control problems, or as reference tracking problems. In both cases, at each time instant, there is a well defined reference trajectory that we seek to make the plant output track. It is well known that in this situation, that non-minimum phase plant zeros pose a limit to the performance achievable in tracking a trajectory. More recently, a range of works have considered a variant of this problem, wherein the path that is to be followed is specified, but the time at which it must be followed is flexible. It has been shown by other researchers that for certain classes of plants and reference trajectories, that this removes some of the difficulties due to non-minimum phase zeros when performing reference tracking. In particular, we are interested in characterising which trajectories can be tracked arbitrarily well in an L2 sense; and for those trajectories that cannot be tracked arbitrarily well, what level of performance is achievable. It turns out that this can be posed as a constrained 'input', null controllability of the zero-dynamics problem, where the constraints are related to the convex hull of the image set of the path.

A.13 Systematic Computation of Ultimate Bounds for Perturbed Systems

Researchers: Maria Seron, Ernesto Kofman (University of Rosario, Argentina), Hernan Haimovich (Student).

The effect of perturbations is a common issue related to the study and analysis of dynamical systems. Perturbations could arise from modelling errors, ageing, uncertainties and disturbances, and are present in any realistic problem. In a typical situation, the exact value of a perturbation variable is unknown but is assumed to be bounded. In the presence of nonvanishing perturbations, that is, perturbations that do not disappear as the state approaches an equilibrium point, asymptotic stability is in general not possible. However, under certain conditions, the system may have ultimately bounded trajectories. A standard tool for ultimate bound estimation is based on the use of Lyapunov functions. This approach is very general and powerful although there is an inherent difficulty associated with the selection of a suitable Lyapunov function.

In this project we have developed a systematic method to compute ultimate bounds for both continuous- and discrete-time perturbed systems. The method is based on a componentwise analysis of the system in modal coordinates and thus exploits the system geometry as well as the perturbation structure without requiring calculation of a Lyapunov function for the system. The method is introduced for linear systems having constant componentwise perturbation bounds and is then extended to the case of state-dependent perturbation bounds. This extension enables the method to be applied to nonlinear systems by treating the perturbed nonlinear system as a linear system with a perturbation bounded by a nonlinear function of the state. Examples have shown that the proposed systematic method may yield bounds that are tighter or at least not worse than those obtained via standard Lyapunov analysis employing quadratic functions. In addition, our method can be combined with Lyapunov analysis to improve on the bounds provided by either approach. Applications and extensions of the method to practical problems such as robust stability and the study of the effects of quantization in sampled-data control systems are currently being developed.

B. Mathematical Systems Theory

Iain Raeburn Program Leader

Jose De Doná Deputy Program Leader

Program Goals

The object of the Program is to investigate mathematical models of dynamic systems which exhibit complex behaviour, exploiting the expertise of the CIs in modern functional analysis. The research will proceed in two broad directions, plus problems driven by a particular application.

B.1 Graph Algebras: Operator Algebras We Can See

Researchers: Iain Raeburn, David Pask, Wojciech Szymanski

Other Support: National Science Foundation (USA)

Directed graphs are simple mathematical structures which are used to model networks and Markov chains. When the network is large or infinite, Hilbert-space representations of the graph provide a powerful tool for analysing the long-term behaviour of the network; the C*-algebra of the graph provides a universal object for studying these representations. Over the past decade, researchers have built an elegant theory which relates the structure of the algebra to the behaviour of cycles in the graph. Researchers in the Functional Analysis group at Newcastle have played a leading role in the development of this theory, and they have been followed by researchers in many other countries, including, Japan, Korea, Canada, Denmark, Spain, and the USA.

In 2004, Iain Raeburn gave the keynote series of ten lectures at a conference in Iowa, and the text of these lectures was published in book form by the American Mathematical Society in June 2005. Several members of the group continue to work on various topics associated to graph algebras. In 2005, Wojciech Szymanski and Jeong Hee Hong (Korea) computed the analytic rank of graph algebras, and James Foster wrote an excellent honours thesis in which he used graph algebras to model a family of non-commutative spaces called quantum balls.

B.2 Higher-rank Graphs

Researchers: Iain Raeburn, David Pask, Aidan Sims, Trent Yeend, John Quigg (Arizona State University, USA), Mikael Rordam (University of Southern Denmark, Denmark).

Higher-rank graphs are higher-dimensional analogues of the directed graphs used to model networks and Markov chains. They were introduced by Kumjian and Pask in 2000 as models for the operator algebras associated to actions of groups on trees and buildings. (Here the word "building" is being used in a technical sense: buildings are higher-order combinatorial structures which play a central role in the theory of algebraic groups, and which have deep links all over the discipline.) As for ordinary directed graphs, each higher-rank graph has a graph algebra which is universal for Hilbert-space representations.

In the past few years, higher-rank graphs and their algebras have begun to attract the same kind of attention that ordinary graph algebras have. Iain Raeburn gave a pair of lectures on higher-rank graphs at a conference in Ireland in June, and was delighted to learn that there is already a great deal of activity in this area in Britain.

A notable achievement in 2005 was the completion of a long paper with Rordam on a family of rank-2 graphs whose algebras can be realised as direct limits of very nice algebras. The family includes examples whose algebras are the algebras associated to irrational rotations in the plane, which are widely as the most fundamental examples of dynamics with complex orbit structure. The prototype of what we hope to be another new family of examples of rank-2 graphs was studied by Natasha Weaver in her honours thesis; she is now enrolled as a PhD student, and following up her honours work should make an unusually exciting PhD project.

B.3 Groupoid Models

Researchers: Iain Raeburn, Trent Yeend, Cynthia Farthing (University of Nebraska, USA), Paul Muhly (University of Iowa, USA)

Other Support: National Science Foundation (USA)

There are several ways in which one can approach the theory of graph algebras, and the theory of graph algebras provides good test problems for the general theories which operator-algebraists use to analyse crossed-product like structures. The most potent of these general theories is that developed by Renault for groupoid algebras, which in our setting provides an algebraic-topological framework intermediary to the directed graph and the C*-algebra.

Groupoid models were used by the Newcastle team in the first analyses of graph algebras in the 1990s, but the models were constructed in an ad hoc fashion. More recently, Paterson has developed a procedure for constructing such models, and applied it to infinite graphs. Farthing, Muhly and Yeend adapted his construction to provide groupoid models for higher-rank graph algebras. In early 2005, as his PhD project, Yeend extended these results to provide a groupoid model for the continuous graphs of Katsura, and then used a similar model to study the higher-rank analogue of Katsura's graphs. He subsequently made good progress on removing some technical hypotheses during the visit of Kumjian to the Centre in July-August.

B.4 Wavelet Bases

Researchers: Iain Raeburn, Kaushik Mahata, Trent Yeend, Nadia Larsen (University of Oslo, Norway), Judy Packer (University of Colorado, USA), Larry Baggett (University of Colorado, USA)

Wavelets are functions on the real line whose translates and dilates form an orthonormal basis for the Hilbert space of square-integrable functions. The miracle is that such functions exist, and a huge effort has gone into constructing them.

In one approach to the construction of wavelets, a central role is played by a pair of operators satisfying an algebraic relation which is very similar to those arising in graph algebras. In 2004, Larsen and Raeburn exploited the geometrical information implicit in this relation to recognise a key step in the construction of wavelets as that of a direct limit of Hilbert spaces. During two brief visits to the University of Colorado, Raeburn discussed this new approach with Packer and Baggett, two mathematicians who are specialists in wavelets. They immediately saw the potential of the new approach, and the discussions in June lead quickly to new applications. These were consolidated in December, and a major priority for 2006 is to finish off this work.

Wavelets, of course, are also central to signal processing, and Raeburn and Yeend had some very promising preliminary discussions with Mahata on how the new approach might shed light on applications to signal processing. This too will be followed up in 2006.

B.5 Symbolic Dynamics and Operator Algebras

Researchers: David Pask, Teresa Bates (University of NSW, Australia), Iain Raeburn, Wojciech Szymanski

A symbolic dynamical system consists of a collection of infinite sequences of symbols from an alphabet, together with a map, called the shift map which moves the sequences from right to left. A special class of symbolic dynamical system is the subshift of finite type, which is closely related to a Markov chain. A subshift of finite type may be modelled by the infinite paths in a directed graph. An important tool for analysing these symbolic dynamical systems is the graph algebra associated to the underlying directed graph. Pask and Raeburn and their co-workers have pioneered the theory of graph algebras, which are infinite dimensional analytical objects capable of encoding the complex dynamics of the associated subshift of finite type. Many dynamical properties of a symbolic dynamical system are captured by the associated graph algebra.

In this current project we seek to extend and expand this close relationship between symbolic dynamical systems and graph algebras. An arbitrary symbolic dynamical system over a given alphabet may be represented by a certain directed graph which carries a labelling by elements from the alphabet. In recent work we have formulated the properties of a labelled graph algebra which subsumes the properties of an ordinary graph algebra. The next step is to develop their algebraic properties in order to examine how the properties of the symbolic dynamical system manifest themselves in the associated labelled graph algebra.

B.6 Nonlinear Analysis and Fixed-Point Theory

Researchers: Brailey Sims, Tomas Benevides (University of Seville, Spain), Sompong Dhompongsa (Chiang Mai, Thailand), Helga Fetter (CIMAT, Mexico), Enrique Llorens Fuster (University of Valencia, Spain), Art Kirk (University of Iowa, USA), Ian Searston (Student), Mark Smith (Student).

Equilibria for discrete and continuous dynamical systems correspond to fixed points of nonlinear maps on infinite dimensional function spaces. The solution of nonlinear optimization and control problems lead to variational inequalities and hence ultimately to fixed points of a related nonlinear operator. When the system is conservative, the nonlinear mapping is nonexpansive with respect to an appropriate metric on the underlying function space. The convergence and ergodic structure of orbits and various iterative schemes, such as those of Ishikawa, relate to the stability and long-term average behaviour of the system.

The project continues to further our fundamental understanding of nonexpansive and related mappings, with an emphasis on identifying easily applied, yet widely applicable, criteria that ensure the existence of fixed points for such maps together with effective algorithms by which they can be approximated. Special emphasis is given to the more difficult cases, where the underlying space lacks nice geometric structure such as that exhibited by a Hilbert space, or where linear structure is absent and so the usual tools of convex analysis are inapplicable. This work includes the following topics:

Analysis in Geodesic Metric Spaces

In many situations the underlying space lacks linear structure. In this context, the existence and stability of fixed points for nonexpansive type mappings depends on the special geometric properties of the space. Hyperconvex metric spaces; for example, the unit ball of l_∞ and R-trees, and classical hyperbolic n-space H_∞ are examples of spaces on which nonexpansive mappings have nonempty fixed point sets. Recently it has been observed that geodesic metric spaces which are hyperbolic in the sense of Gromov, in particular the so called CAT(0) spaces, encompass many of these examples and provide a very general setting in which a rich fixed point theory paralleling that for Banach spaces is being developed.

Also under investigation is how such spaces may provide a natural and fertile setting for many other aspects of system dynamics and optimal control when an intrinsic linear structure is absent.

Applications of Ultra-Methods to Nonlinear Analysis

Banach space ultra-products, and more recently ultra-powers of metric spaces, have proved a powerful and important tool in both linear and nonlinear analysis. And represent a common meeting ground between standard and non-standard analysis. They have proved the major tool for establishing the existence of fixed points for nonexpansive and asymptotically nonexpansive maps in the absence of normal structure, and are particularly suited to the analysis of attainment problems. By lifting the problem to an ultra-power approximate solutions become a solution. For example, an approximate eigenvalue of a linear operator corresponds to an eigenvalue of the lifted operator. The further development of these techniques and their potential application to a wide variety of problem remains an ongoing focus of this project. A research monograph on this topic by the project leader and one of his students (Mark Smith) is soon to be published by Springer.

C. Bayesian Learning

Kerrie Mengersen QUT Node Program Leader

Richard Gerlach NU Program Leader

Program Goals

The Bayesian Learning Program comprises researchers from both Engineering and Statistics backgrounds, reflecting the strong interdisciplinary nature of the Centre. Five main areas of research are identified in the program: system identification, Markov Chain Monte Carlo (MCMC) methods, Bayesian modelling, nonlinear and mixture modelling, and robot location and vision.

The Bayesian Learning Program continued to grow and consolidate in 2004. The program was successfully divided into two nodes in 2004. One node is located at QUT Brisbane, led by CI Mengersen, and the other remains at the University of Newcastle, led by CI Gerlach. CI Mengersen remains Program Leader. Major administrative activities included recruitment of personnel to the Program and the relocation of part of the Program to QUT in Brisbane.

Major research activities included development of new theoretical and applied research topics, creation of research papers, conduct of an international workshop, conduct of short courses for academics and industry, participation in conferences, hosting of international visitors and collaboration with other members of CDSC. These activities are detailed below.

C.1 Flexible Distributions

Researchers: Robert King, Richard Gerlach, Paul Rippon (Student), Darren Wraith (Student), Kerrie Mengersen

Flexible distributions such as the generalised lambda, g-and-k and g-and-h, are all defined by their inverse distribution function. They are of interest because of the wide variety of distributional shapes that they can take on. Research in this theme focused on two topics: flexible regression and flexible process control.

Regression using Flexible Distributions

We developed a new parametric regression method that models the residuals with these distributions. This allows for severe departures from normality. A paper on this topic is currently under review.

Process Control using Flexible Distributions

Three activities were undertaken as part of this topic.

Petra Graham completed and submitted her thesis on statistical methods for assessing and improving quality. A paper on reliability trees, which extend classification and regression trees to include information on precision, has been submitted.

A Bayesian approach to constructing process control charts using g-and-k distributions was developed by Mengersen in collaboration with UQ researcher Dr Michele Haynes. A paper on this topic was published in a refereed international journal in 2005. This research is ongoing in collaboration with King and Rippon.

A contract research project ($130K) was funded by the Queensland Environmental Protection Agency as an outcome of our work on Bayesian Learning and flexible models. The project contributed to monitoring water quality in the Great Barrier Reef. Using twice-daily satellite images (depicted below), we identified sampling sites using Bayesian mixture models, then identified appropriate g-and-k distributions to describe two water quality indicators, chlorophyll and turbidity. Novel control charts based on these distributions were then constructed. One such chart is illustrated below. These techniques are being further pursued in collaboration with QEPA and CSIRO.

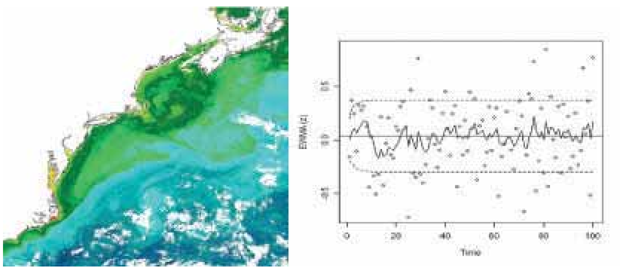


Figure 6

C.2 Mixture Models

Researchers: Kerrie Mengersen, Richard Gerlach, Ross McVinish, Darren Wraith (Student), Clair Alston (Student), Elizabeth Stojanovski (Student)

This research theme focused on three topics: nonparametrics, mixtures and meta-analysis.

Nonparametrics

We developed Bayesian nonparametric methods for the estimation of densities using triangular distributions. Conditions have been established for strong and weak consistency of the posterior distribution. This figure illustrates the goodness of fit of estimation under this approach.

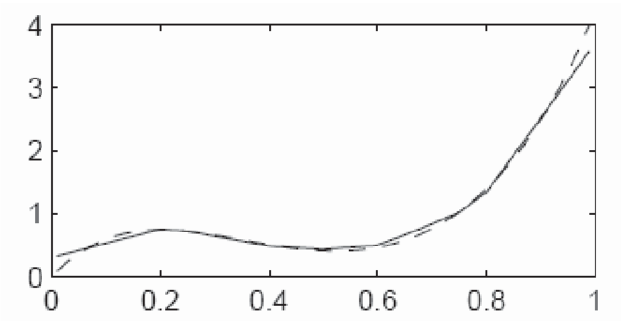


Figure 7

We developed a test for a uniform or parametric family against a nonparametric alternative using these triangular mixtures. This work involved international collaboration with Dr Judith Rousseau of University Paris and CREST. The research comprised part of an invited presentation coauthored by Mengersen and McVinish and others at the International Statistical Institute (ISI) meeting in Sydney in April 2005, and resulted in the submission of a paper to the Annals of Statistics. This work is currently being extended to the analysis of circular data.

A Bayesian approach was also developed for determining set membership for the transfer function describing a simple plant. For the controller to be robust it is necessary to have an estimate of the uncertainty about the model – including unmodeled dynamics.

A Bayesian-decision theoretic approach was developed for the quantification of model error in transfer function estimation of linear input-output systems. It is demonstrated that the prior used in the estimation of the transfer function leads to a consistent estimate. A bound on the rate of convergence of the posterior is also determined. The required quantities can be computed routinely using reversible jump Markov chain Monte Carlo.

This approach has connections to a well established method for examining this problem called set membership identification. The two approaches differ in the type of prior information that can be incorporated and in the probabilistic nature of the error bounds formed. Furthermore, it is shown that the results from set membership identification have a Bayesian – decision theoretic interpretation.

This work has led to one paper presented at an international modeling workshop (IWSM) in 2005 and another accepted for presentation in 2006 (SYSID).

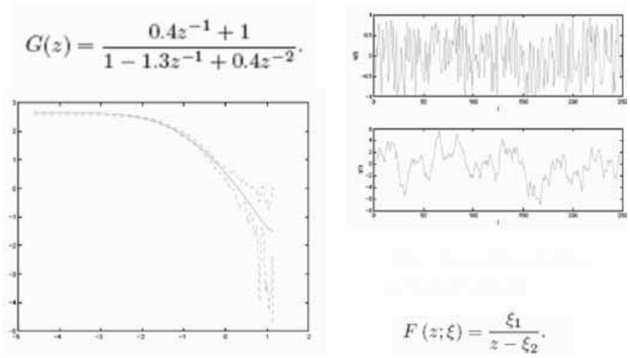


Figure 8

Mixtures

PhD student Clair Alston developed Bayesian mixture models to describe interpretable components or clusters in a CAT scan image. Spatio-temporal models were developed that better take account of the positive autocorrelation of neighbouring pixels in the images and to describe the progression of the mixture components over time.

This work has led to the publication of two papers in an international refereed journal and the submission of a third paper.

Mengersen was also invited to co-author a chapter on Bayesian Mixtures for the Encyclopedia of Statistics.

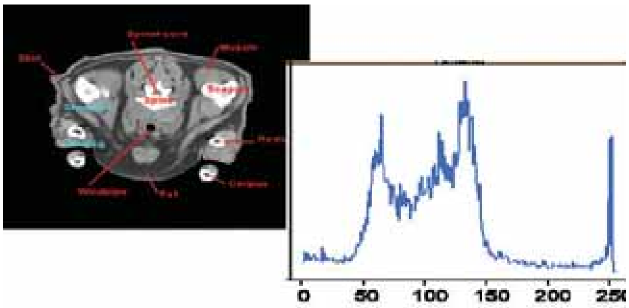


Figure 9

Meta-Analysis

PhD student Liz Stojanovski and supervisor Mengersen completed two refereed chapters on meta-analysis, to appear in the Encyclopedia of Pharmaceutical Sciences.

PhD student Darren Wraith and supervisor Mengersen co-authored two papers that introduce and apply multivariate Bayesian meta-analysis methods for the assessment of the association between smoking, asbestos exposure and lung cancer. The papers have been accepted by Statistics in Medicine and Statistical Methods in Medical Research.

C.3 Time Series Models

Researchers: Richard Gerlach, Darfiana Nur, Zahirul Hoque

This research theme has continued to focus on the development of new methods for analysing time series models, in particular: nonlinear time series, threshold models and Gaussian smooth threshold autoregressive (GSTAR) models.

Dr Richard Gerlach has continued his research into Bayesian techniques for variable selection and model selection, using novel MCMC. Recent interest has focused on identifying thresholds in nonlinear time series. Applications include finance, EEG modelling and industrial control. As part of this work, Gerlach was coauthor of an invited paper.

Dr Darfiana Nur has continued her work on Bayesian analysis of Gaussian smooth threshold autoregressive (GSTAR) models, leading to a paper accepted for publication.

Dr Zahirul Hoque has been collaborating with Gerlach, extending his previous research on the preliminary test estimator of a simple linear dynamic regression model via Kalman filtering. This has led to the submission of a refereed journal article. He is also collaborating with a pioneer in this area, Professor Saleh, Carleton University, Canada. The aim is to generalise the work for a more general case of an adaptive Kalman filter.

C.4 Computational Methods

Researchers: Kerrie Mengersen, Richard Gerlach, Darfiana Nur, Ross. McVinish, Ian Wood, David Allingham, Kate Lee (Student)

This project comprised four topics in 2005.

Darfiana Nur and Kerrie Mengersen concluded research on phase randomization, used as a convergence diagnostic for MCMC. Theoretical results confirming these conclusions were also derived. A paper on this topic has appeared in a refereed journal and another is under review.

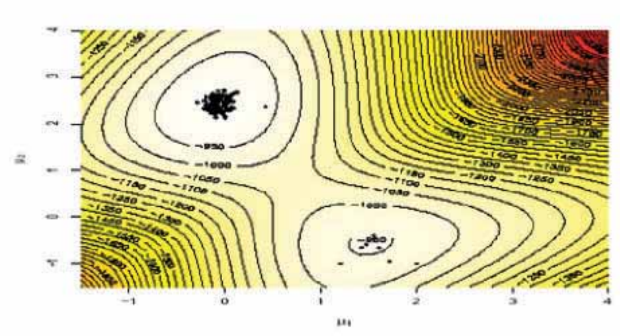


Figure 10

Ms Kate Lee, a new PhD student, is investigating new types of Markov chain Monte Carlo algorithms for simulating from complex distributions. She has improved a 'pinball sampler' proposed by Mengersen and Robert (2000) through the addition of tempering.

MCMC has also been considered in novel solutions of complex problems. Richard Gerlach and coauthors have adapted and compared Markov chain Monte Carlo algorithms in finance and neurology. Richard Gerlach also developed Bayesian techniques for variable selection and model selection in the identification of thresholds in nonlinear time series, with applications in finance, EEG modelling and industrial control. This research has led to an impressive ten journal papers published or accepted in 2005.

Paul Rippon (PhD student) and Mengersen wrote an invited chapter for the Encyclopedia of Information Science. Mengersen was also invited to provide an updated review of Markov chain Monte Carlo methods for the Encyclopedia of Biostatistics.

C.5 Complex Systems

Researchers: Kerrie Mengersen, Julio Braslavsky, Paul Rippon (Student), Petra Graham (Student)

This research theme comprised three topics in 2005: Bayesian learning in genetics, Bayesian networks and links to other Programs in the Centre.

Bayesian Learning in Genetics

Mengersen and former PhD student Peter Baker completed research into the use of Bayesian mixture models for estimation in the face of large amounts of missing data. This has led to the publication of a refereed journal article.

Dr Ian Wood has begun developing new methods for comparative mapping. His work with Mengersen on Bayesian meta-analysis of association studies, undertaken in collaboration with a local biotechnology company Genetic Solutions, was accepted with minor revision by Genetic Selection and Evolution.

Bayesian Networks

We are developing Bayesian Belief Networks to integrate scientific and management information about lyngbya (a form of blue-green algae exacerbated by industrial pollution) in Deception Bay, Queensland. This algae and an example of the associated network are depicted below. The project commenced as a consultancy ($30K) and developed into a two-year funded research contract ($181K) in collaboration with Healthy Waterways, the Brisbane City Council and various industry groups. The technical questions of interest are the appropriate integration of quantitative and qualitative sources of information, introduction of stochastics in deterministic models, and combination of diverse models. This work has led to a presentation at an international meeting, publication of a refereed conference paper and preparation of a refereed journal article.

The modelling and analysis of industrial emissions and their impact on health and the environment will become a stronger feature of this Program in 2006.

Collaboration with Industry Projects

The Bayesian Learning Program actively collaborates with other Programs in the Centre as appropriate. For example, Research Associate David Allingham provides a direct link with the industry projects, with work on mine planning, particle filters and dynamic networks and bioleaching. In the latter project, he has been involved in Matlab programming for the bioleaching model and the application of particle filters to state and parameter estimation.

David Allingham has also been involved in researching the application of dynamic Bayesian networks (DBNs) for the BHP-Billiton flotation tank fault-detection project. The example of interconnected tanks is a common one in papers and theses on this subject, so should be readily applicable to this project. It combines the Bayesian practice of updating belief distributions, using observed data and likelihood functions, with the dynamical equations underlying such a system. Many types of faults (e.g. pipe build-up, burst failures and measurement failures) can be detected using the DBN approach.

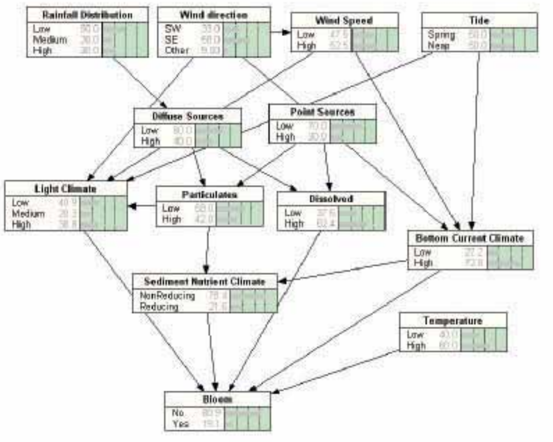
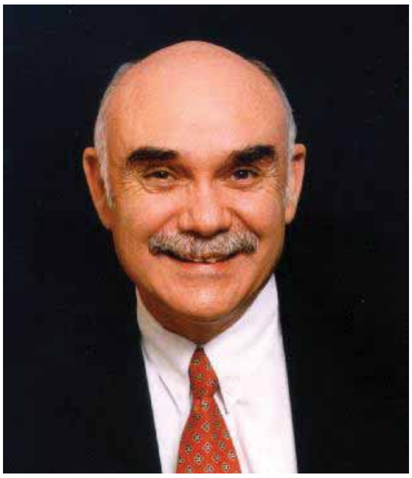


Figure 11

D. Signal Processing

Minyue Fu Program Leader



Graham Goodwin Deputy Program Leader

Program Goals

This Program focuses on model-based signal processing. Research problems include physical modelling, system identification, model validation, prediction, filtering, and signal recovery. Examples of this type of signal processing are adaptive control, Kalman filtering, communications channel equalization, and multi-user detection for wireless communications. Much of the fundamental research for model-based signal processing is related to other Programs. But the aim of this Program is to promote applications of modelling, control and estimation in various signal processing problems.

D.1 Direct Identification of Continuous-time Stochastic Processes

Researchers: Kaushik Mahata, Minyue Fu

Direct algorithms for estimating continuous-time ARMA (CARMA) models are considered in this project. In this approach, time-series data are used to estimate the half spectrum of the process which is then used to fit a rational model for the process. The proposed algorithm delivers much more reliable estimates than standard indirect modeling approaches which rely on estimating an intermediate discrete-time model. We have also developed a direct estimation algorithm to work for multi-variable processes.

D.2 Analytic Interpolation and Applications

Researchers: Kaushik Mahata, Minyue Fu

Analytic interpolation problems are encountered frequently in various disciplines like spectrum analysis, model reduction and controller synthesis. In this project we study the solvability of a generalized versions of Nevanlinna-Pick interpolation problem and the Covariance extension problem, where the degree of the interpolating function is restricted to a particular value, and the number of the interpolation constraints is larger than the degree. We have given the conditions for the uniqueness and the existence of the solution. In addition, we have developed computationally efficient algorithms which can handle a large number of noise-corrupted interpolation data. Our algorithm provides a reliable and accurate solution to the problem. The techniques are used in spectral analysis of discrete-time signals.

D.3 Representation of Linear Systems in the Time-Frequency Domain

Researchers: Damian Marelli, Minyue Fu

The subband technique involves representing a linear system in the time-frequency domain. This technique can be used for system approximation, system identification, channel equalization, etc., with the advantage of having a very high numerical efficiency. However, the analysis of this technique is not trivial and its optimal setup is not clear. In this project we propose a functional analysis setting for the analysis of the subband technique, which leads us to new results on system approximation and system identification. For the problem of system approximation, we provide an analytical expression for calculating the optimal subband approximation of a given system. For the problem of system identification, we provide a novel identification method which allows us to build a high-quality model using a number of "low-quality" subband models which are easily computable. This identification method reduces the computational complexity of the identification process significantly when compared with conventional system identification methods.

D.4 Synthesis of High-Fidelity Digital Waveguide Sound

Researcher: Damian Marelli

In this project we investigate the application of the subband technique for system approximation to real-time implementation of a high-fidelity sound synthesis method called Digital Waveguide Synthesis. Generally speaking, this method uses a model based on the physics of the sound source, which uses a closed loop containing a filter (loop filter) with linear magnitude but non-linear phase. The implementation of the loop filter in the time domain is very expensive computationally, which limits the application of this type of models for real-time applications. We aim at simplifying the complexity of this kind of models by implementing the loop filter using the subband technique. For this application, the time delay introduced by the subband technique is a critical problem, as the subband model must work in closed loop. To cope with this problem, we use non-diagonal, critically-sampled subband models, with a relatively high number of non-diagonal terms. Using this strategy we are able to implement the Digital Waveguide Synthesis method for the synthesis of piano sounds in real-time.

D.5 Signal Sampling and Recovery

Researchers: Graham Goodwin, Arie Feuer (The Technion, Israel), Milan Derpich (Student), Daniel Quevedo

Motivated by motion compensated filtering in image processing we have considered the problem of sampling and reconstruction of signals with sampling rates below the Nyquist rate. It has been assumed that temporal dependence can be induced via motion. In this fashion the data consists of both spatial and temporal sampling. In this framework, we have analysed the conditions for perfect reconstruction for a number of typical motions.

In related work we have studied the problem of multi-dimensional signal reconstruction from nonuniform or generalized samples. Typical solutions in the literature for this problem, utilize continuous filtering. The key result arising from our work is a multi-dimensional "interpolation" identity which establishes the equivalence of two multi-dimensional processing operations. One of these uses continuous domain filters while the other uses discrete processing. The results expand and generalize earlier work by other authors on the one dimensional case. Potential applications include 2D images and video signals.

D.6 Use of the EM Algorithm for Identification of Nonlinear Systems

Researchers: Graham Goodwin, Juan Carlos Aguero (Student)

We have studied use of estimation algorithms from the Expectation – Maximization (EM) family for parameter estimation in linear and nonlinear stochastic models. Comparisons have been drawn between the linear and nonlinear cases. A new algorithm has been proposed for the linear case which allows structural information to be incorporated. Also, a novel algorithm has been developed for the nonlinear case which captures some of the key features of the linear case.

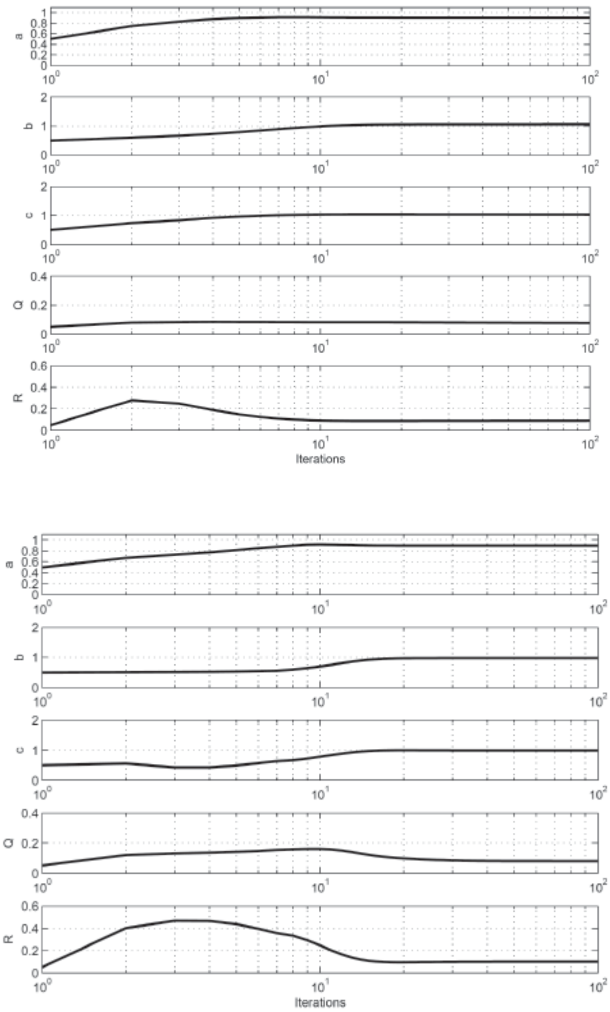


Figure12: Parameter Estimation via EM Algorithm

D.7 Sampled Data Models for Nonlinear Systems

Researchers: Graham Goodwin, Juan Yuz (Student)

This project is concerned with the relationship between continuous time models and their discrete time counterparts for nonlinear systems.

Models for continuous-time nonlinear systems typically take the form of ordinary differential equations. To utilize these models in practice, with sampled data, requires discretisation. This raises the question of the relationship between the model describing the sampled data and the original continuous-time model. We have shown how accurate sampled-data models can be obtained for deterministic nonlinear systems. These models include extra zero dynamics that have no counterpart in the original continuous-time systems. The results generalize well-known results for the linear case. We have also explored the implications of these results in nonlinear system identification. Our most recent work focuses on sampled data models for nonlinear stochastic systems.

D.8 Robustness Issues in Continuous-Time System Identification from Sampled Data

Researchers: Graham Goodwin, Juan Yuz (Student), Hugues Garnier (Université Henri Poincaré, France)

In this project we have explored the robustness issues that arise in the identification of continuous-time systems from sampled data. A key observation is that in practice one cannot rely upon the fidelity of models at high frequencies. This implies that any result which implicitly or explicitly depends upon the folding of high frequency components down to lower frequencies will be inherently nonrobust. We have illustrated this point by referring to the identification of continuous time auto-regressive stochastic models from sampled data. We argue that traditional approaches to this problem are sensitive to high frequency modeling errors. Accordingly, we have proposed alternative procedures with enhanced robustness properties.

D.9 Errors in Variables Estimation

Researchers: Graham Goodwin, Juan Carlos Agüero (Student) Mario Salgado (Universidad Técnica Federico Santa María, Chile)

There exists a substantial literature dealing with the problem of errors-in-variables identification. It is known, for example, that there is an equivalence class of models that give compatible descriptions of the input-output data. In this project, we have imposed a mild restriction so as to avoid certain singular possibilities. This leads to a parameterization of the equivalence class of models in the SISO case via a single real parameter. We have then used this result to show that there exists a model which minimizes the maximal weighted infinity norm of the error between the chosen model and all members of the equivalence class. This model is unique and is independent of the weighting function used in the infinity norm. It is thus the natural choice to be used in applications such as robust control. The result is also compared with more conventional estimates provided by prediction error methods. We have also used the result to establish necessary and sufficient conditions for unique identifiability in SISO errors in variable problems.

E. Process Control and Optimisation

Rick Middleton Program Leader

Julio Braslavsky Deputy Program Leader

Program Goals

The partnerships between researchers and industry enable reciprocal transfer of knowledge and new ideas of great potential impact on the community and economy. This Program encompasses four research projects motivated by and in collaboration with industrial partners. The main underlying theme of these projects is the application of advanced control and optimisation techniques to maximise asset utilisation and production in selected industrial processes of significant complexity. The complexity of the dynamics of such processes arise from factors including model errors, unknown disturbances, nonlinearities, distributed parameter systems, elements of Human Machine Interaction and hybrid (Discrete and Continuous State) components. Expected outcomes of the Program include high quality research solutions tailored to the needs of the Australian industry.

E.1 Integrated Mine Planning (BHP Billiton)

Project Leader: Rick Middleton

Researchers: Bryan Hennessy (Student), Graham Goodwin, Merab Menabde (BHP-Billiton), Maria Seron, Peter Stone (BHP-Billiton), Mei Mei Zhang.

This project aims to investigate financial optimisation, under a range of constraints and uncertainties, in open cut mining. The financial return is frequently quantified by the Net Present Value (NPV) of a mine, however, this is inevitably subject to uncertainty. The long term aim is to permit risk, uncertainty and 'real options' (such as purchase of additional equipment; or moth balling of equipment for portions of the life of the mine) to be incorporated in optimal mine planning decisions.

In 2005, Rick Middleton (till July) thence Graham Goodwin (Aug-Dec) have taken a project leadership role. Early work extended examination of the Genetic Algorithm (GA) based optimisation solutions. These results showed that compared with the Mixed Integer Linear Programming (MILP) solutions, the GA offered substantial advantages in computational time, for low to moderate accuracy solutions, however, for high accuracy solutions, MILP appeared to be preferable in the problems examined. However, should some problem formulations not admit representation in MILP form, in which case other solution techniques, such as GA, need to be examined.

The project's focus has now shifted to stochastic optimisation, where we explicitly take account of the uncertainty in the material price in the schedule optimisation. Initially, we are using a simple log-normal mean reverting price model, to capture the distribution and correlations in metal price.

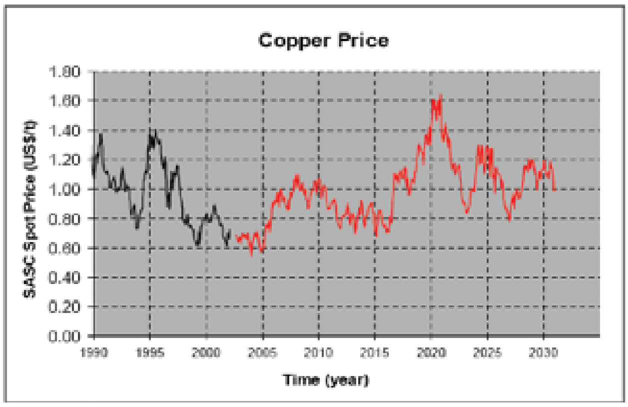


Figure 13: Example price history, and sample path of possible future prices

Based on this, we can then examine various strategies for optimising the mining schedule taking account of these variations. These optimisations, in their most sophisticated form, will involve stochastic optimisation 'with recourse', as we take account not only of the distribution of future prices, but also the fact that in the future, decisions will be taken on the basis of price and other information available at the time. These optimisation problems may be computationally very expensive if pursued from a Monte Carlo perspective, and it therefore becomes important to have good algorithms for selecting a small number of representative scenarios.

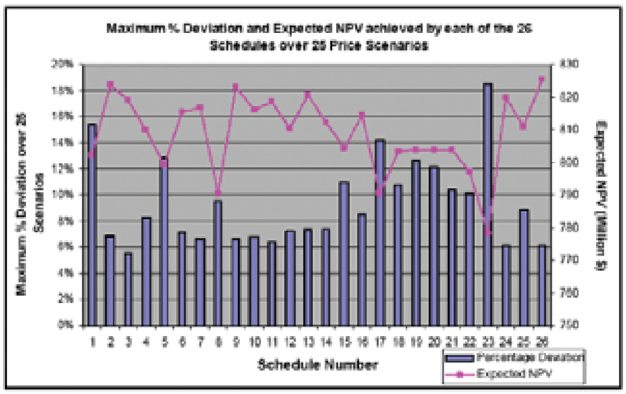


Figure 14: Example comparison of 'open loop' performance, versus optimal (with future knowledge performance) over 25 Monte Carlo scenarios.

This leads naturally to the problem of scenario selection, which is currently a hot topic within stochastic optimisation theory, which will be examined as part of this project. Within this context, it is natural to consider jump Markov processes and other models of price, to allow selection of a small number of scenarios which accurately reflect the distribution of future price behaviour.

E.2 Optimisation Based Operator Guidance Schemes (BHP-Billiton Innovation)

Project Leader: Julio Braslavsky

Researchers: David Allingham, Mark Downey, Boris Godoy (Student), Graham Goodwin, Tom Honeyands, Katrina Lau, Jim Lee, Arthur Maddever, Rick Middleton, John Truelove, Bob Turner.

This project, funded by a partnership between the Centre with BHP Billiton Innovation (Newcastle), deals with the optimisation of novel technologies for industrial processes whose complexity requires significant human intervention for continuous operation. The project aims to develop optimised solutions based on mathematical modelling, and state-of-the-art model based control and estimation tools. The project encompasses two Industrial Case Studies described below.

Modelling and Control of Copper Heap Leaching

This Industrial Case Study focuses on the development and refinement of mathematical models aimed at the control and optimisation of the heap leaching technology for copper extraction.

Heap Leaching is a technology for copper extraction from low copper content ores. As compared to the smelting technology, the leaching technology is carried out at much lower temperatures and thus eliminates the generation of environmental pollutants such as sulphur dioxide, although effluents and residues must be treated.

In heap leaching the crushed ore is piled in large heaps on top of which a raffinate solution is sprinkled. The raffinate dissolves the copper and leaves a gangue residue as it percolates through the heap. Important catalysts in the process are certain bacteria, which convert the metal compounds into their water-soluble forms.

Leachates are collected at the bottom of the heap, and after solvent extraction, metallic copper is obtained by electrowinning, the raffinate is recycled to the heap.

To date, a low complexity model of a heap leaching process has been completed and satisfactorily parametrised against an experimentally validated, high complexity model developed by BHP Billiton. Such low complexity models have been developed based on physical principles, and simplified to the process dynamics most relevant for control purposes, resulting in a complexity reduction of at least an order of magnitude with respect to BHP Billiton's high complexity model. The low complexity model will be presented in a paper accepted for the 14th IFAC Symposium on System Identification, SYSID-2006, to be held in Newcastle in March 2006.

In addition, a Matlab interface has been coded to manage the feedback operation of BHP Billiton's high complexity model, and the prototyping of estimation and feedback control strategies, currently under study.

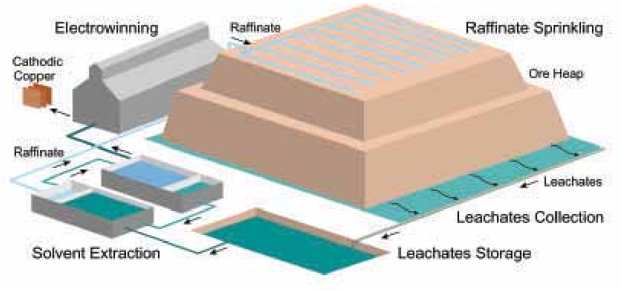


Figure 15: Heap leaching process schematic

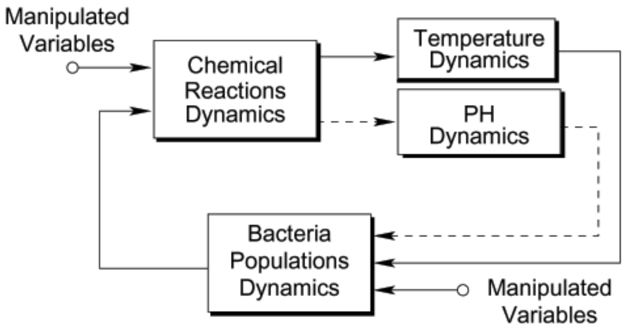


Figure 16: Dynamic structure of the heat leaching low complexity model

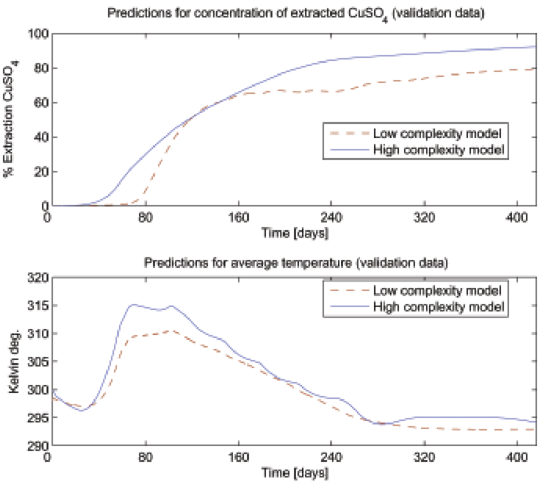


Figure 17: Comparative simulation runs of the heap leaching low complexity model

Sferics Reduction in Electromagnetic Mineral Exploration

This Industrial Case Study deals with the reduction of sferics noise in mineral exploration using Geo-Ferret, an Australian designed and developed electromagnetic (EM) exploration technology recently acquired by BHP Billiton.

In EM exploration technologies such as Geo-Ferret, a time-varying primary EM field is generated by a transmitter loop on the earth surface. This primary EM field induces superficial electrical currents in the ground, which in turn induce electrical currents at greater depths. The decaying induced currents in the earth generate a secondary EM field, which can be measured by an array of receivers on the earth surface. The magnitude and rate of decay of such secondary EM fields depend on the electrical conductivity of the ground, which, through detection and processing, allows the identification and location of target underground mineral bodies.

Sferics, a low frequency electromagnetic radiation arising from lightning strikes, is a major contributor to the noise in Geo-Ferret receivers. The performance of the receivers is such that sferics would dominate the sensor noise in some environments (sferics are much higher nearer the equator). The objective of the project is to reduce the contribution of sferics to the Geo-Ferret system noise through data processing, making use of some of its distinguishing characteristics, such as correlation between receivers, temporal and spatial characteristics of the disturbance and target signals, and characteristic frequency distributions.

Work on this Industrial Case Study has started in October 2005 with a review of studies on sferics removal techniques. Towards the end of 2005, a preliminary mathematical model for the induced currents in target underground ore bodies and overburden has been developed, including a proposed statistical characterisation of sferics noise. Such a model and characterisation will be parametrised and validated against field data collected early in 2006.

An implementation of the techniques developed into Geo-Ferret operations would be dependent on the success in the noise reduction study.

Figure 18: Receivers in electromagnetic exploration with Geo-Ferret

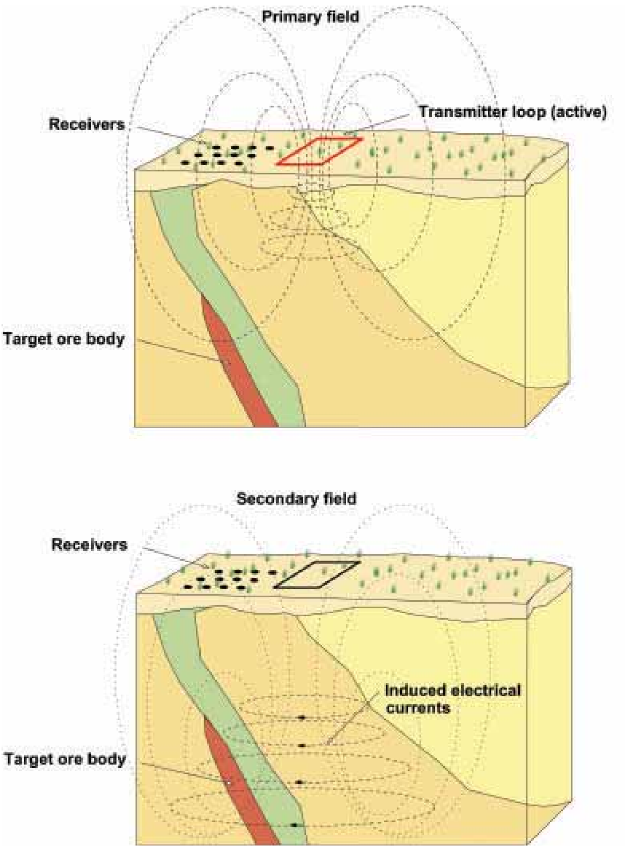


Figure 19: General principle of time domain electromagnetic mineral exploration

Figure 20: Sferics are low frequency electromagnetic radiation largely produced by lightning strikes (Image credit University Corporation for Atmospheric Research, Photo by Carlye Calvin)

E.3 Next Generation Model Based Control Tools (Matrikon)

Project Leader: Greg Adams

Researchers: Graham Goodwin, Mina Kardani, Adrian Medioli (Student), Rick Middleton, Maria Seron, Richard Thomas (Matrikon), James Welsh

The aim of this industry project is to deliver to Matrikon process control tools that allow

- appropriate handling of complex, nonlinear and heterogeneous processes;
- robust and easy-to-use system identification;
- economic optimisation of process variables;
- integration of control tools with monitoring and diagnostic tools; and
- extensive human-machine interaction support.

Development has concentrated on enhancing existing MPC software from Matrikon, and integrating knowledge and existing closed-loop identification software from CDSC. Matrikon developers and CDSC researchers have so far implemented a number of high-priority features to enhance marketability and usefulness of the current MPC toolbox. CDSC researchers have also been active in several areas – work completed thus far includes:

- Range control for process outputs.
- QP algorithm improvements.
- Investigation of multi-level constraints.
- A priori checks for steady-state infeasibility.
- Investigation of constraint shedding strategies.

For the closed-loop identification tools, enhancements to the algorithm and the user interface have been implemented, and the software has been delivered to Matrikon in beta form. Matrikon are currently evaluating the software and further development is being discussed. Matrikon's existing autotuning software is also being enhanced.

In more general areas, a review of non-linear MPC was completed, and tools for steady-state economic optimisation were added as the result of a final year project from Ivan Berry.

Benchmarking problems have been evaluated, including the Shell control problem, a binary distillation column, the Tennessee Eastman Challenge process, and a grinding mill problem. The MPC code and identification code have been tested on these problems, with encouraging results.

Matrikon engineers in Canada are also applying the MPC tools to several industrial applications, and Matrikon engineers in Newcastle are testing the identification software on a five-input, five-output industrial problem.

Work currently under investigation is focussed on:

- Closed-loop identification for non-square systems, and introducing more descriptive model and data quality measures.
- Decoupling strategies for MPC.
- Simple checks for dynamic infeasibility.

Future work on next-generation model-based control tools will investigate:

- Input/output selection issues (i.e. how to handle the case where an actuator or sensor fails). Incorporating robust MPC strategies. Incorporating multi-level constraints and dynamic feasibility checks. Further work on infeasibility handling and constraint shedding.
- Developing strategies for control of non-linear processes. Extending and integrating the economic optimisation features. Extension of diagnostic features for operators.
- Finishing the closed-loop identification software, and integrating the software into Matrikon's product family.
- More extensive testing on benchmarking problems, and applying the tools to more industrial processes.

The next two years promise to be a period of intensive research and development in this project. Over 2006, it is hoped to have the main features added for initial testing, and for applied research to be conducted. Further enhancements and full delivery aim to be achieved by the end of 2007.

F. Mechatronics

Reza Moheimani Program Leader

Rick Middleton Deputy Program Leader

Program Goals

Many technical processes and products in the area of mechanical and electrical engineering show an increasing integration of mechanics with electronics and information processing. This integration is between the components (hardware) and the information-driven functions (software), resulting in integrated systems called mechatronic systems. The development of mechatronic systems involves finding an optimal balance between the basic mechanical structure, sensor and actuator implementation, automatic digital information processing and overall control, and this synergy results in innovative solutions. The practice of mechatronics requires multidisciplinary expertise across a range of disciplines such as: mechanical engineering, electronics, information technology, and decision-making theories. These complicated interactions generate a rich and complex set of dynamic behaviours to be analysed and controlled. This program is aimed at investigating such analysis and control questions in emerging mechatronic systems.

F.1 PPF Control of Vibration

Researchers: Reza Moheimani, Benjamin Vautier, Bharath Bhikkaji

A major difficulty in controlling flexible structures is due to the fact that they are distributed parameter systems. Consequently, these structures have a very large number of vibration modes and their transfer functions contain many poles close to the $j\omega$ axis. These systems are generally difficult to control. In most cases a small number of in-bandwidth modes of the structure are required to be controlled, and it is possible that some in-bandwidth modes are not targeted to be controlled at all. The presence of uncontrolled modes can lead to the problem of spillover. That is, the control energy is channeled to the residual modes of the system and this process may destabilize the closed-loop system. In particular, the spillover effect is of major concern at higher frequencies where obtaining a precise model of the structure is rather difficult.

One approach to overcome the spillover effect is based on using collocated sensors and actuators. Positive Position Feedback control originally proposed by Caughey and co-authors is an control design technique for flexible structures with collocated sensors and actuators, which is insensitive to the spillover effect. The PPF controller does not guarantee unconditional stability of the closed-loop system, however, it does guarantee stability in presence of uncontrolled in-bandwidth modes, and it has the additional property that it rolls off quickly at higher frequencies.

One of the shortcomings of PPF is that the effect of out-of-bandwidth modes on the dynamics of the controlled modes is ignored. Dynamics of distributed parameter systems such as flexible structures are governed by partial differential equations. These PDEs are discretized to obtain a lumped model of the system. Consequently, the transfer functions of flexible structures consist of a very large number of highly resonant terms. Out-of-bandwidth terms are often removed from the model to simplify the task of designing a controller. This introduces an error that manifests itself by perturbing in-bandwidth zeros of the system, which could be detrimental to the closed-loop stability of the controlled system. In particular, when the actuators and sensors are collocated, this effect is exacerbated. This problem can be alleviated by adding a feed-through term to the truncated model of the system. This amounts to approximating the transfer function.

$$G(s) = \sum_{i=1}^{M} \frac{\psi_i \psi_i'}{s^2 + 2\zeta_i \omega_i s + \omega_i^2}$$

with

$$G^N(s) = \sum_{i=1}^{N} \frac{\psi_i \psi_i'}{s^2 + 2\zeta_i \omega_i s + \omega_i^2} + D$$

Therefore, the stability conditions for the PPF controller need to be rederived accordingly.

A PPF control system is shown in Figure 21. The controller, K(s) has the following structure

$$K_{pp}(s) = \sum_{i=1}^{\tilde{N}} \frac{-\gamma_i \gamma_i'}{s^2 + 2\delta_i \tilde{\omega}_i s + \tilde{\omega}_i^2}$$

Closed-loop stability of the system is guaranteed if the following linear matrix inequalities hold

$$\Delta > 0$$

$$\begin{bmatrix} \Omega^2 & -\Psi'\Gamma & 0 \\ -\Gamma'\Psi & \tilde{\Omega}^2 & \Gamma' \\ 0 & \Gamma & D^{-1} \end{bmatrix} > 0$$

where

$$Z = \begin{bmatrix} \zeta_1 & & & \\ & \zeta_2 & & \\ & & \ddots & \\ & & & \zeta_N \end{bmatrix}; \quad \Omega = \begin{bmatrix} \omega_1 & & & \\ & \omega_2 & & \\ & & \ddots & \\ & & & \omega_N \end{bmatrix}$$

$$\Psi = \begin{bmatrix} \psi_1 & \psi_2 & \dots & \psi_N \end{bmatrix}$$

and

$$\Delta = \begin{bmatrix} \delta_1 & & & \\ & \delta_2 & & \\ & & \ddots & \\ & & & \delta_{\tilde{N}} \end{bmatrix}$$

$$\tilde{\Omega} = \begin{bmatrix} \tilde{\omega}_1 & & & \\ & \tilde{\omega}_2 & & \\ & & \ddots & \\ & & & \tilde{\omega}_{\tilde{N}} \end{bmatrix}$$

$$\Gamma = \begin{bmatrix} \gamma_1 & \gamma_2 & \dots & \gamma_{\tilde{N}} \end{bmatrix}$$

Therefore the set of stabilizing PPF controllers is a convex set. A number of multivariable PPF controllers have been designed for a test structure consisting of a cantilevered beam and several bonded piezoelectric actuators and sensors. Although a drastic simplification of a real structure, a thin beam is dynamically well understood, retains the important characteristics of the real structure and is an ideal experimental testbed to evaluate performance of the PPF controllers.

Experimental setup is depicted in Figure 22. The performance of a PPF controller is illustrated in Figure 23. During the experiment a mass was added to the free end of the beam which resulted in significant perturbation of in-bandwidth resonance frequencies of the structure. As illustrated in Figure 23, the PPF controller maintains closed-loop stability and performance of the system.

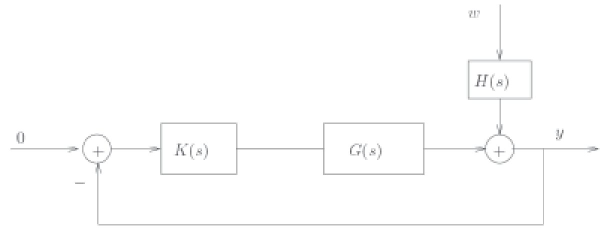


Figure 21: A PPF control system

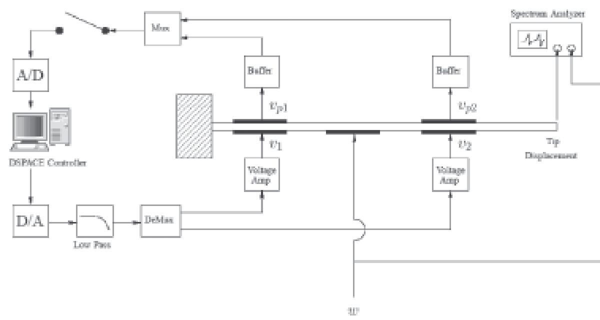


Figure 22: Schematics of the experimental testbed

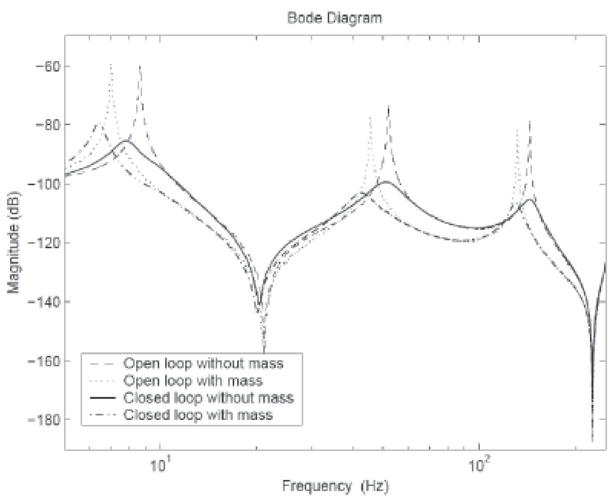


Figure 23: Open-loop vs closed-loop FRF of the PPF controlled cantilevered beam

F.2 Sensor-less Active Noise Control in an Acoustic Enclosure

Researchers: Reza Moheimani, Andrew Fleming, Dominik Niederberger (ETH, Switzerland); Manfred Morari (ETH, Switzerland)

Low-frequency reverberant sound fields are usually suppressed by means of either adaptive feedforward control or Helmholtz resonator, as illustrated in Figure 24(a) and (b). Feedforward systems utilize a noise reference signal, error microphone, and loudspeaker to cancel sound propagating in one direction. Due to the requirement for multiple transducers and a powerful Digital Signal Processor, feedforward systems are the most complex and expensive option for acoustic noise reduction. Helmholtz resonators, comprising of auxiliary coupled acoustic chambers, are a popular passive technique for the control of dominant acoustic modes. Although lightly damped acoustic modes can be heavily attenuated, the resonators are difficult to tune and require impractically large cavity volumes at frequencies below 200 Hz. The purpose of this research is to introduce a new technique for the control of low-frequency reverberant sound fields. By connecting an electrical impedance to the terminals of an acoustic loudspeaker, as illustrated in Figure 24, the mechanical dynamics, and hence acoustic response of the composite system can be made to emulate a sealed acoustic resonator. No microphone or velocity measurement is required in this approach. In some cases, the required electrical circuit is simply the parallel connection of a capacitor and resistor. Experimental application to a closed acoustic duct, pictured in Figure 25 results in 14 dB pressure attenuation of a single acoustic mode. Active impedances can be designed by viewing the system model from a feedback control perspective. The resulting electrical impedances, although not passive, are experimentally shown to attenuate four acoustic modes by up to 10 dB, as shown in Figure 26.

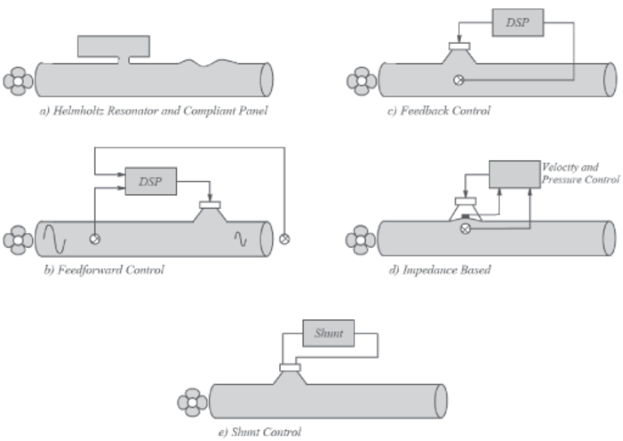


Figure 24: Available noise control techniques (a)-(d); and the proposed sensor-less approach (e)

Figure 25: The acoustic enclosure used in sensor-less ANC experiment

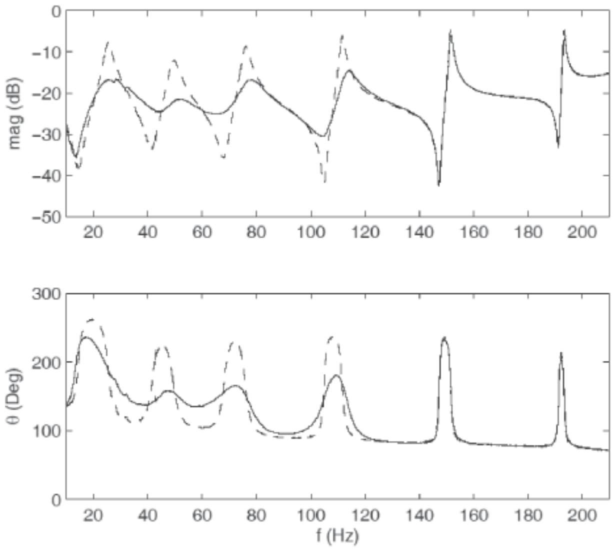


Figure 26: The first four modes of the acoustic enclosure are attenuated by 9.3, 9.5, 8.3, and 8.8 dB respectively.

F.3 A Grounded Load Charge Amplifier for Reduction of Hysteresis in Piezoelectric Actuators

Researchers: Reza Moheimani, Andrew Fleming

Since the late 1980s, it has been known that driving piezoelectric transducers with current or charge rather than voltage significantly reduces hysteresis. Simply by regulating the current or charge, a significant reduction in the hysteresis can be achieved. However, due to perceived difficulties associated with driving piezoelectric loads, which are inherently highly capacitive, with charge/current amplifiers this unique property of piezoelectric materials has rarely been utilized. Piezoelectric actuators are being driven by voltage amplifiers almost universally.

Although the circuit topology of a charge or current amplifier is much the same as a simple voltage feedback amplifier, the uncontrolled nature of the output voltage typically results in the load capacitor being charged up. Saturation and distortion occur when the output voltage, referred to as the compliance voltage, reaches the power supply rails. The stated complexity invariably refers to the need for additional circuitry to avoid charging of capacitive loads.

This research resulted in a new class of grounded-load charge amplifiers free from DC and low-frequency voltage drift. As shown in Figure 27, the new circuitry consists of a voltage loop and a charge loop for low- and high- frequency operation of the device respectively. The device, pictured in Figure 28, has been tested in the lab and very encouraging results have been obtained; see Figure 29.

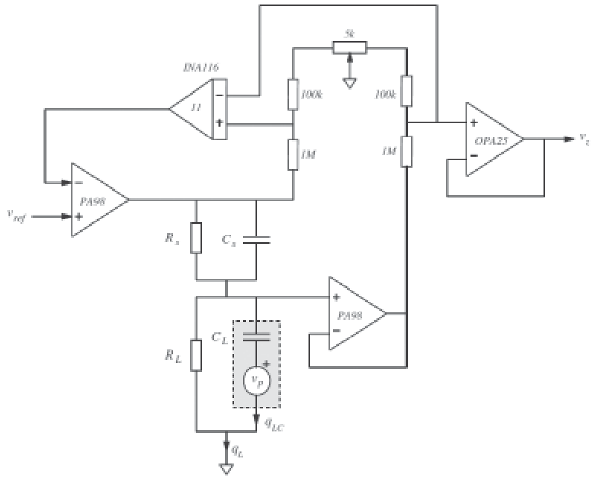


Figure 27: Schematics of a grounded load charge amplifier

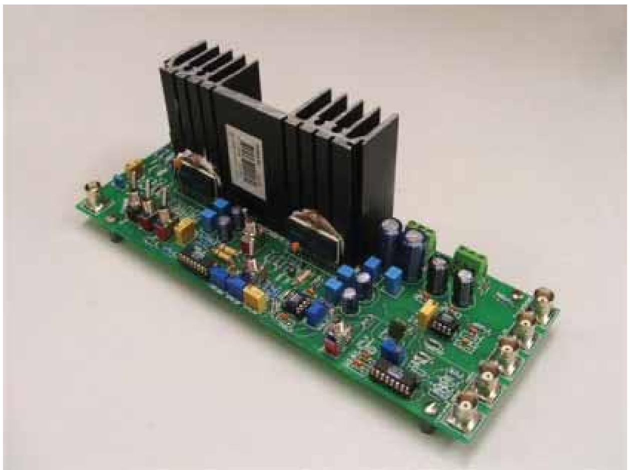


Figure 28: Picture of the charge/current amplifier

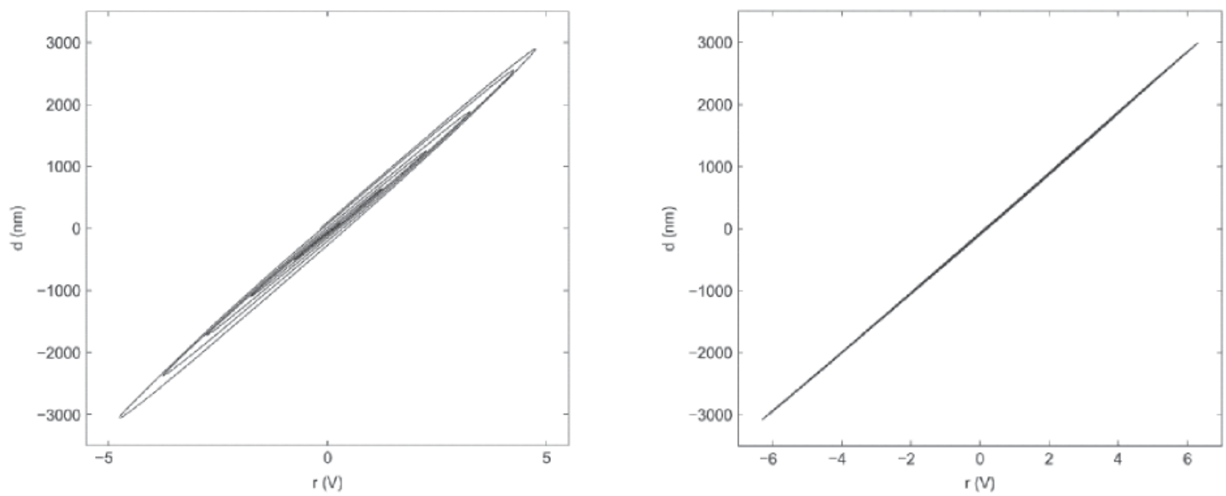


Figure 29: Hysteresis observed in a piezoelectric actuator is significantly reduced when it is driven by charge.

F.4 Robot Soccer and Rescue

Researchers: Rick Middleton, Robert King, Stephan Chalup, Michael Quinlan, Timothy Moore (Student), Joshua Marshall (Student)

Figure 30: Rescue robot work area at Robocup 2005, Osaka

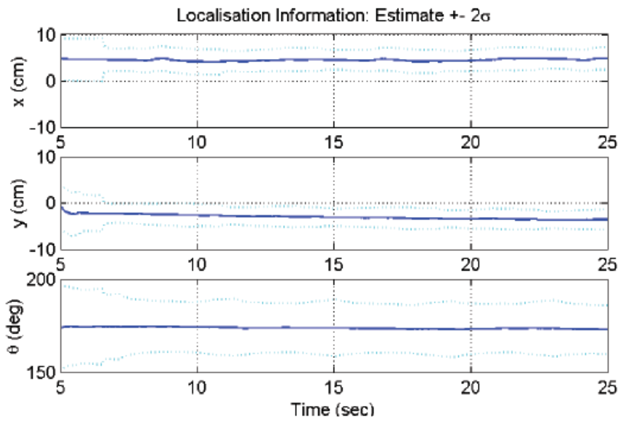


Figure 31: Test data for localisation confidence bounds

The robotics work for CDSC expanded this year to include entry into the Robocup Rescue league, focusing on using autonomous or semi-autonomous robots for disaster area search and recovery. This was the first year we entered the competition. Our work focuses on a tracked vehicle, fitted with custom electronic hardware for the appropriate sensing, communications and drive electronics. We have been able to successfully demonstrate various video, audio and gas sensing capabilities together with the basic communications infrastructure for the system. Whilst not highly placed this year in the competition, progress in the short time available has been good.

The Robocup soccer team has worked on a range of improvements to the system, including a number of enhancements to the vision system ('Soft' colour classification, 7bit colour lookup tables; edge detection algorithms; use of additional fixes (such as implementation of odometry nonlinearities in the EKF; clipping of robot orientation when viewing a goal; use of multiple models) in the localisation algorithms for Robocup.

These, and other enhancements performed extremely well in the competition, and after coming runners in the Australian Open held in April 2004, we were placed 2nd in both the challenge component, and the soccer competition of Robocup, only being beaten by in a penalty shoot out in the grand final with the German Team.

Activity Plan for 2006

Some of our main plans for 2006 are:

- The 2006 Advisory Board Meeting to be held on 28 April 2006 at the Centre in Newcastle.
- 2006 Centre Retreat is tentatively scheduled for July 2006. This will have a major focus on strategic planning and the forthcoming review.
- Centre Review is scheduled for 12 September 2006. This review will cover both current progress and future directions for the Centre.
- With the recent support from the NSW State Government we will be expanding our push for new local (Newcastle) industry based projects.

Publications 2005

Books

J.G. Falset, E.L. Fuster and B. Sims (Editors), "Fixed Point Theory and Applications", Yokohama Publishers, 2004[1].

I. Raeburn, Graph Algebras, CBMS Regional Conference Series in Mathematics, Vol. 103, Amer. Math. Soc., 2005, 113 pages.

Chapters in Books

G.C. Goodwin and A. Feuer*, "*Control*", Chapter in Encyclopedic Reference of Neuroscience. Editors U. Windhorst, M. Binder and N. Hirokawa, Springer, to appear.

G.C. Goodwin and A. Feuer*, "*Adaptive Control*", Chapter in Encyclopedic Reference of Neuroscience. Editors U. Windhorst, M. Binder and N. Hirokawa, Springer, to appear.

J.-M Marin*, K. Mengersen, C.P. Robert*, "*Bayesian Mixtures*", Invited Chapter in Handbook of Statistics Vol. 25, on Bayesian Statistics. Editors D. Dey and C.R. Rao. Elsevier.

P. Rippon and K. Mengersen, "*Bayesian Learning*", Invited Chapter in Encyclopedia of Information Science. Editor M. Khosrow-Pour. Information Resources Management Association, USA.

C.J. Seysener, C.L. Murch and R.H. Middleton, "*Extensions to Object Recognition in the Four Legged League*", in Lecture Notes in Computer Science, RoboCup 2004: Robot Soccer World Cup VIII: Vol 3276/2005 ed. D. Nardi, M. Riedmiller, C. Sammut et al.

E. Stojanovski and K.L. Mengersen, "*Multivariate Meta-Analysis*", Encyclopedia of Pharmaceutical Sciences. To appear. (15pp.)

E. Stojanovski and K.L. Mengersen, "Bayesian Meta-Analysis". Encyclopedia of Pharmaceutical Sciences. To appear. (15pp.)

Books in Preparation

G.C. Goodwin, A Bastiani and F. Sobora, "*Virtual Laboratories for Control System Design*", in preparation.

S.O.R. Moheimani and A.J. Fleming, "*Piezoelectric Transducers for Vibration Control and Damping*", Springer-Verlag, ISBN 1-84628-331-0. To appear in 2006.

B. Sims and M.L. Smith, "*Ultramethods in Analysis*".

Patents

G.C. Goodwin, R.H. Middleton, P. Stone and M. Menabde, "*Mine Planning Optimization*", Australian Provisional Patent, April 2005.

International Plenary/Keynote Addresses

M. Fu, "Dynamic Modeling and Analysis of Iterative Decoding Processes". Keynote speech at *5th Int. Conf. Control and Automation*, June 2005.

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[1] Omitted from the 2004 report

* International Co-Author

K. Mengersen, "Bayesian Risk Assessment: Combining Multiple Exposures". Invited presentation for the NZSA, Dunedin, July 2005.

I. Raeburn, "Higher-rank graph algebras", *Operator Algebras and Applications*. (Two one-hour lectures), National University of Ireland, Cork, June 2005

I. Raeburn, "Extending representations and nonabelian duality", *GPOTS 2005*, University of Central Florida, Orlando, June 2005.

B. Sims, Series of five invited lectures on "Metric Fixed Point Theory" to the *Special Workshop on Analysis*, Centro de Investigacion en Matematics, Guanajuato, Mexico April 2004 [I].

B. Sims and M.L. Smith, "New results using Banach and metric space ultraproducts", *Fourth World Congress of Nonlinear Analysts*, Orlando, Florida, June-July 2004 [I].

B. Sims, "Developments in metric fixed point theory", *Seventh International Conference on Fixed Point Theory and Applications*, Guanajuato, Mexico, July 2005.

Invited Lectures/Presentations

R. King, "*Investigating Response Times with the Generalised Lambda Distribution*". Invited presentation SSAI NSW Branch, Sydney, June 2005.

K. Mengersen, "*Epidemiological Risk Assessment: Combining Multiple Exposures*". Invited presentation SSAI Qld Branch, March 2005.

K. Mengersen, "*Bayesian Mixtures of Triangular Distributions*". Invited presentation for IWSM, Sydney, July 2005.

K. Mengersen, "*Integrating Different Sources of Information: Putting Our Money Where Our Bayesian Mouth Is*". Invited Cornish Lecture, Adelaide, October 2005

K. Mengersen, with C. Alston, P. Kuhnert, S. Low Choy and R. McVinish. "*Bayesian Model Selection: Review and Discussion*". Invited Discussion, 55th Session of the International Statistical Institute, Sydney, NSW 2005.

Edited Special Issues

S.O.R. Moheimani (Guest Ed.). "Focused Section on Smart Materials and Structures", *IEEE/ASME Transactions on Mechatronics*, Vol.2, 2005.

Journal Papers (published)

S. Allen, D. Pask and A. Sims, "A dual graph construction for higher rank graphs, and K-theory for finite 2-graphs", *Proc. Amer. Math.* Soc. 134, pp.455-464, 2005.

C.L. Alston, K. Mengersen, J.M. Thompson, P.J. Littlefield, D. Perry and A.J. Ball, "Bayesian spatial mixture models for sheep CAT scan images", *Aust. J. Agricultural Research*, Vol.56, pp.373-388, 2005.

P. Baker, K. Mengersen and G. Davis, "A Bayesian approach to reconstructing centrally censored distributions", *J. Agricultural, Biological and Environmental Statistics*, Vol.10, No.1, pp.61-83, 2005.

S. Behrens, A.J. Fleming and S.O.R Moheimani, "Passive vibration control via electromagnetic shunt damping", *IEEE/ASME Transactions on Mechatronics*, Vol.10, No.1, pp.118-122, February 2005.

C.W.S. Chen*, M.K.P. So* and R. Gerlach, "Assessing and testing for threshold nonlinearity in stock returns", *Australian and NZ Journal of Statistic*, Vol.47, No.4, pp.473-488, 2005.

C.W.S. Chen*, M.K.P. So* and R. Gerlach, "Asymmetric response and interaction of US and local market news in financial markets", *Applied Stochastic Models in Business and Industry*, Vol.21, No.3, pp.273-288, 2005.

S. Easton and R. Gerlach, "Interest rates and the 2004 Australian Election", *Australian Journal of Political Science*, Vol.40, No.4, pp.559-566, 2005.

C. Farthing*, P.S. Muhly* and T. Yeend, "Higher-rank graph C*-algebras: an inverse semigroup and groupoid approach", *Semigroup Forum*, Vol.72, pp.159-187, 2005.

A. Feuer*, A. Allouche* and G.C. Goodwin, "Motion aided sampling and reconstruction", *IEE Proceedings on Vision, Image and Signal Processing*, Vol.152, No.1, pp.115-121, 2005.

A. Feuer* and G.C. Goodwin, "Reconstruction of multi-dimensional bandlimited signals from nonuniform and generalized samples", *IEEE Transactions on Signal Processing*, Vol.53, No.11, pp.4273-4282, 2005.

A.J. Fleming and S.O.R. Moheimani, "A grounded load charge amplifier for reducing hysteresis in piezoelectric tube scanners", *Review of Scientific Instruments*, Vol.76, No.7, July 2005.

A.J. Fleming, S.O.R. Moheimani and S. Behrens, "Synthesis and implementation of sensor-less active shunt controllers for electromagnetically actuated systems", *IEEE Transactions on Control Systems Technology*, Vol.13, No.2, pp.246-261, March 2005.

A.J. Fleming and S.O.R. Moheimani, "Control oriented synthesis of high performance piezoelectric shunt impedances for structural vibration control", *IEEE Transactions on Control Systems Technology*, Vol.13, No.1, pp. 98-112, January 2005.

M. Fu, "Stochastic analysis of turbo decoding", *IEEE Transactions on Information Theory*, Vol.51, No.1, pp.81-100, January 2005.

M. Fu and L. Xie*, "The sector bound approach to quantized feedback control", *IEEE Transactions on Automatic Control*, Vol.50, No.11, pp.1698-1711, November 2005.

J. Glaria*, T. Wendler and G.C. Goodwin, "An introductory model of a one-piston engine", *European Journal of Physics*, Vol.26, pp.1115-1125, 2005.

G.C. Goodwin, J.A. De Doná, M.M. Seron and X.W. Zhuo, "Lagrangian duality between constrained estimation and control", *Automatica*, Vol.41, No.6, pp.935-944, 2005.

G.C. Goodwin, M.E. Salgado* and E.I. Silva*, "Time-domain performance limitations arising from decentralized architectures and their relationship to the RGA", *International Journal of Control*, Vol.78, No.3, pp.1045-1062, 2005.

M.A. Haynes and K. Mengersen, "Bayesian estimation of g-and-k distributions using MCMC", *Computational Statistics*, Vol.20, pp.7-30, 2005.

M. Hunter, R. Smith, W. Hyslop, O. Rosso*, R. Gerlach, J. Rostas and D. Williams, "The Australian EEG database", invited paper in special edition of *Clinical EEG and Neuroscience*, Vol.36, pp.76-81, 2005.

[I] Omitted from the 2004 report

* International Co-Author

K. Lau, G.C. Goodwin and R.T. M'Closkey*, "Properties of modulated and demodulated systems with implications to feedback limitations", *Automatica*, Vol.41, pp.2123-2129, 2005.

D. Marelli and M. Fu, "A subband approach to channel estimation and equalization for DMT and OFDM systems," *IEEE Transactions on Communications*, Vol.53, No.11, pp.1850-1858, November 2005.

D.Q. Mayne, M.M. Seron and S. Rakovic, "Robust model predictive control of constrained linear systems with bounded disturbances", *Automatica*, Vol.41, pp.219-224, 2005.

S.O.R. Moheimani, "Introduction to the focused section on smart materials and structures", *IEEE/ASME Transactions on Mechatronics*, Vol.10, No.2, pp.133-134, April 2005.

S.O.R. Moheimani and B.J.G. Vautier, "Resonant control of structural vibration using charge-driven piezoelectric actuators", *IEEE Transactions on Control Systems Technology*, Vol.13, No.6, pp.1021-1035, November 2005.

D. Nur, K. Mengersen and R. Wolff, "Phase randomisation: A diagnostic test for MCMC", *Aust. N.Z. J. Statistic*, Vol.47, pp.309-322, 2005.

D. Pask, J. Quigg* and I. Raeburn, "Coverings of k-graphs", *J. Algebra*, Vol.289, pp.161-191, 2005.

I. Raeburn and A. Sims, "Product systems of graphs and the Toeplitz algebras of higher-rank graphs", *J. Operator Theory*, Vol.53, pp.399-429, 2005.

O. Rosso*, W. Hyslop, R. Gerlach, R.L. Smith, J.P. Rostas, and M. Hunter, "Quantitative EEG analysis of maturational changes associated with childhood absence epilepsy", *Physica A*, Vol.356, No.1, pp.184-189, 2005.

B.J.G. Vautier and S.O.R. Moheimani, "Charge-driven piezoelectric actuators for structural vibration control: Issues and implementation", *Smart Materials and Structures*, Vol.14, No.4, pp.575-586, August 2005.

D.J. Woodhouse and R.H. Middleton, "Consistency in ground potential rise estimation utilising fall of potential method data", *IEEE Transactions on Power Delivery*,Vol.20, No.2, pp.1226-1234, 2005.

J. Yuz, G.C. Goodwin, A. Feuer* and J.A. De Doná, "Control of constrained linear systems using fast sampling rates", *Systems and Control Letters*, Vol.54, No.10, pp.981-990, 2005.

J.I Yuz and G.C. Goodwin, "On sampled-data models for nonlinear systems", *IEEE Transactions on Automatic Control, Special Issue on System Identification: Linear vs. Nonlinear*, Vol.50, No.10, pp.1477-1489, 2005.

Journal Papers (Accepted for publication)

S. Allen, "A gauge invariant uniqueness theorem for corners of k-graph algebras". Accepted for publication in *Rocky Mount. J. Math*.

T. Bates and D. Pask, "C*-algebras of labelled graphs". Accepted for publication in *J. Operator Theory*.

C.W.S. Chen*, M.J. Yang, R. Gerlach and H.J. Lo, "The asymmetric reactions of stock returns to international and domestic information based on a four regime double threshold GARCH model". Accepted for publication in *Physica A*.

S. Echterhoff*, S. Kaliszewski*, J. Quigg* and I. Raeburn, "A categorical approach to imprimitivity theorems for C*-dynamical systems". Accepted for publication in *Memoirs Amer. Math. Soc.*

A.J. Fleming, S. Behrens and S.O.R. Moheimani, "Proof-mass vibration control using a shunted electromagnetic transducer". Accepted for publication in *IEEE/ASME Transactions on Mechatronics*.

A.J. Fleming, S.O.R. Moheimani, "Sensorless vibration suppression and scan compensation for piezoelectric tube nanopositioners". Accepted for publication in *IEEE Transactions of Control Systems Technology*, Vol.14, No.1, pp.33-44, 2006.

R. Gerlach, C.W.S. Chen*, S.Y.Lin and M.H. Huang, "Asymmetric responses of international markets to trading volume". Accepted for publication in *Physica A*, Vol.360, No.2, pp.422-444, 2006.

R. Gerlach and F. Tuyl, "MCMC methods for comparing stochastic volatility and GARCH models". Accepted for publication in *International Journal of Forecasting*, Vol.22, No.1, pp 92-107, 2006.

R. Gerlach, P. Wilson and R. Zurbruegg R, "Structural breaks and diversification: The impact of the 1997 Asian crisis on markets in the Pacific". Accepted for publication in *Journal of International Money and Finance*.

A. Feuer*, G.C. Goodwin and M. Cohen*, "Generalization of results on vector sampling expansion". Accepted for publication in *IEEE Signal Processing*.

M. Fu, "Minimum switching control for adaptive tracking". Accepted for publilcation in *International Journal of Adaptive Control and Signal Processing*.

G.C. Goodwin, M.M. Seron, B. Hennessy, R.H. Middleton, P. Stone, M. Zhang and M. Menabde, "Receding horizon control applied to optimal mine planning". Accepted for publication in *Automatica*, Vol. 42, No.8, August, 2006.

H. Haimovich, M.M. Seron and G.C. Goodwin, "Geometric characterisation of multivariable quadratically stabilising quantisers". Accepted for publication in *The International Journal of Control*.

L. Hanlen and M. Fu, "Wireless communication systems with spatial diversity: A volumetric approach". Accepted for publication in *IEEE Transactions on Wireless Communications*, Vol.5, No.1, pp.43-155, January 2006.

M.A. Haynes and K.L Mengersen, "Bayesian estimation of g-and-k distributions using MCMC". Accepted for publication in *Computational Statistics*.

J. H. Hong** and W. Szymanski, "Analytic rank of graph algebras and quantum space". Accepted for publication in *Bull. London Math. Soc*.

E.J. Kofman*, H. Haimovich and M.M. Seron, "A Systematic Method to Obtain Ultimate Bounds for Perturbed Systems". Accepted for publication in *The International Journal of Control*.

W.A. Kirk* and B. Sims, "An ultrafilter approachto locally almost nonexpansive maps". Accepted for publication in *Journal of Functional Analysis*.

K. Lau, D.E. Quevedo, B.J.G. Vautier, G.C. Goodwin and S.O.R. Moheimani, "Design of modulated and demodulated controllers for flexible structures". Accepted for publication in *Control Engineering Practice*.

* International Co-Author

S.-M. Lee, C.W.S. Chen*, R. Gerlach and L.-H. Hwang, "Estimation of Rickers two release method: A Bayesian approach". Accepted for publication in *Australian and NZ Journal of Statistics*.

K. Mahata and M. Fu, "Modeling continuous-time processes via input-to-state filters". Accepted for publication in *Automatica*.

D. Marelli, "Functional analysis approach to subband system approximation and Identification". Accepted for publication in *IEEE Transactions on Signal Processing*.

D. Marelli and M. Fu,"Ergodic properties for multirate linear systems". Accepted for publication in *IEEE Transactions on Signal Processing*.

S.O.R. Moheimani, B.J.G. Vautier and B . Bhikkaji, "Experimental implementation of extended multivariable PPF control on an active structure". Accepted for publication in *IEEE Transactions on Control Systems Technology*.

Z. Mustafa and B. Sims, "A new approach to generalized metric spaces". Accepted for publication in *Journal of Nonlinear and Convex Analysis*.

D. Niederberger*, S. Behrens, A.J. Fleming, S.O.R. Moheimani and M. Morari*, "Adaptive electromagnetic shunt damping". Accepted for publication in *IEEE/ASME Transactions on Mechatronics*.

D. Nur, M.G. Nair and N.D. Yatawara, "Efficient estimation in smooth threshold autoregressive models", Accepted for publication in *Statistics*.

D. Pask and A. Rennie, "The noncommutative geometry of graph algebras". Accepted for publication in *J. Funct. Anal*.

A. Sims, "Gauge-invariant ideals in the C*-algebras of finitely aligned higher-rank graphs". Accepted for publication in *Canadian J. Math*.

A. Sims, "Relative Cuntz-Krieger algebras of higher-rank graphs". Accepted for publication in *Indiana Univ. Math. J*.

W. Su and M. Fu, "Robust stabilization of nonlinear cascaded systems". Accepted for publication in *Automatica*.

I. Wood, G. Moser, D. Burrell, K. Mengersen and J. Hetzel, "A meta-analytic assessment of a Thyroglobulin marker for marbling in beef cattle". Accepted for publication in *Genetic Selection and Evolution*.

N.D. Yatawara, M.G. Nair and D. Nur, "Bayesian analysis of Gaussian smooth threshold autoregressive (GSTAR) models". Accepted for publication in *Computational Statistics and Data Analysis*.

Conference Papers

J.C. Agüero, G.C. Goodwin and M.E. Salgado*, "On the optimal estimation of errors in variables models for robust control", *Proc. 16th IFAC World Congress on Automatic Control*, Prague, Czech Republic, July 4-8, 2005.

J.H. Braslavsky, R.H. Middleton and J.S. Freudenberg*, "Effects of time delay on feedback stabilization over Signal-to-Noise Ratio constrained channels", *Proc. 16th IFAC World Congress on Automatic Control*, Prague, Czech Republic, July 4-8, 2005.

J. H. Braslavsky, R.H. Middleton and A. Rojas, "Control over a bandwidth limited signal to noise ratio constrained communication channel", *Proc. 44th IEEE Conference on Decision and Control/European Control Conference*, Seville, Spain. 12-15 December 2005.

T. Dalby and B. Sims, "Banach lattices and the weak fixed point property", *Proc. of the Seventh International Conference on Fixed Point Theory and Applications*, Guanajuato, Mexico, July 2005.

A.J. Fleming and S.O.R. Moheimani, "Sensor-less vibration suppression and scan compensation for piezoelectric tube nanopositioners", *Proc. 44th IEEE Conference on Decision and Control/European Control Conference*, Seville, Spain. 12-15 December 2005.

A. J. Fleming and S.O.R. Moheimani, "Proof-mass inertial vibration control using a shunted electromagnetic transducer", *Proc. 16th IFAC World Congress on Automatic Control*, Prague, Czech Republic, July 4-8, 2005.

J.S. Freudenberg*, J.H. Braslavsky, and R.H. Middleton, "Control over signal-to-noise ratio constrained channels: Stabilization and performance", *Proc. 44th IEEE Conference on Decision and Control/European Control Conference*, Seville, Spain. 12-15 December 2005.

M. Fu, "Stochastic analysis of turbo decoding", *International Conference on Communications*, Seoul, May 2005.

M. Fu and S. Hara*, "Quantized feedback control for sampled-data systems," *Proc. 16th IFAC World Congress on Automatic Control*, Prague, Czech Republic, July 4-8, 2005.

M. Fu and K. Mahata, "Generalizations of the Nevanlinna-Pick interpolation problem", *Proc. 44th IEEE Conference on Decision and Control/European Control Conference*, Seville, Spain. 12-15 December 2005.

G.C. Goodwin, J.I. Yuz and H. Garnier*, "Robustness issues in continuous-time system identification from sampled data", *Proc. 16th IFAC World Congress on Automatic Control*, Prague, Czech Republic, July 4-8, 2005.

G.C. Goodwin and J.C. Agüero, "Approximate EM algorithms for parameter and state estimation in nonlinear stochastic models", *Proc. 44th IEEE Conference on Decision and Control/European Control Conference*, Seville Spain. 12-15 December 2005.

H. Haimovich and M.M. Seron, "On optimum quantization density for multiple-input systems", *Proc. 44th IEEE Conference on Decision and Control/European Control Conference*, Seville, Spain. 12-15 December 2005.

N.S. Larsen* and I. Raeburn, "From filters to wavelets via direct limits", *Proc GPOTS*, Orlando Florida, June 7-12, 2005.

B. Lennartson*, R.H. Middleton, A.-K. Christiansson*, and C.-M. Fransson*, "On the choice of sampling rate and anti-alias filter using multi criteria H_∞ control", *Proc. 16th IFAC World Congress on Automatic Control*, Prague, Czech Republic, July 4-8, 2005.

K. Mahata and M. Fu, "Modeling continuous-time processes via input-to-state filters", *Proc. 16th IFAC World Congress on Automatic Control*, Prague, Czech Republic, July 4-8, 2005.

K. Mahata and M. Fu, "On constrained covariance extension problem", *Proc. 44th IEEE International Conference on Decision and Control/European Control Conference*, Seville, Spain, 12-15 December 2005.

J. Mare and J. De Doná, "Dynamic programming solution of state estimation problems with constrained disturbances", *Proc. 16th IFAC World Congress on Automatic Control*, Prague, Czech Republic, July 4-8, 2005.

* International Co-Author

J. Mare and J. De Doná, "Analytical solution of constrained reference tracking problems by dynamic programming", *Proc. 44th IEEE Conference on Decision and Control/European Control Conference*, Seville, Spain. 12-15 December 2005.

R. McVinish, "A Bayesian approach to set membership for transfer functions", *Proc. International Workshop on Statistical Modelling*, Sydney, 2005.

A.M. Medioli, M.M. Seron and R.H. Middleton, "Best possible region of attraction for a class of unstable systems using short horizon MPC concepts", *Proc.44th IEEE Conference on Decision and Control/European Control Conference*, Seville, Spain. 12-15 December 2005.

S.O.R. Moheimani, B.J.G. Vautier and B. Bhikkaji, "Multivariable PPF control of an active structure", *Proc.44th IEEE Conference on Decision and Control/European Control Conference*, Seville, Spain. 12-15 December 2005.

A. Rojas and R. H. Middleton, "Phase analysis for 2-D weakly coupled oscillatory systems", *2005 American Control Conference*, Portland, June 2005.

A. Rojas, J.H. Braslavsky, and R.H. Middleton, "Control over a bandwidth limited signal to noise ratio constrained communication channel", *Proc. 44th IEEE Conference on Decision and Control/ European Control Conference*, Seville, Spain. 12-15 December 2005.

M. M. Seron, Kyung Sang Yoo* and G.C. Goodwin, "Backlash compensation using receding horizon control", *Proc. 16th IFAC World Congress on Automatic Control*, Prague, Czech Republic, July 4-8, 2005.

B.J.G. Vautier and S.O.R. Moheimani, "Multivariable LQG vibration control using charge-driven piezoelectric actuators", *Proc. 16th IFAC World Congress on Automatic Control*, Prague, Czech Republic, July 4-8, 2005.

I. Wood, G. Moser and K. Mengersen, "Comparative mapping of genomes", *Proc. International Workshop on Statistical Modelling*, Sydney, 2005.

J.I. Yuz and G.C. Goodwin, "Generalised filters and stochastic sampling zeros", *Proc. 44th IEEE Conference on Decision and Control/European Control Conference*, Seville, Spain. 12-15 December 2005.

X.W. Zhuo, J.A. De Doná and M.M. Seron, "Explicit solution to constrained linear estimation", *Proc. 16th IFAC World Congress on Automatic Control*, Prague, Czech Republic, July 4-8, 2005.

Industry Technical Reports

Industrial Automation Services Pty. Ltd.

IAS/05/1
G.C. Goodwin and O.J. Rojas. Confidential Report No. 3, January 2005.

IAS/05/2
G.C. Goodwin and O.J. Rojas, Confidential Report No. 4, January 2005.

IAS/05/3
G.C. Goodwin, "Preliminary Report to IAS on Control", June 2005.

IAS/05/4
G.C. Goodwin, Confidential Report", June 2005.

IAS/05/5
G.C. Goodwin and D.E. Quevedo, Confidential Report, November 2005.

BHP Billiton Innovation

BHPB/IMP/05/1
M.M. Zhang, "An Algorithm Combining Genetic Algorithms and Topological Sorting on Mine Scheduling Problems", January 2005.

BHPB/IMP/05/2
G.C. Goodwin, M.M. Seron and R.H. Middleton, "Integrated Mine Planning (A Control Engineering Viewpoint)", January 2005.

BHPB/IMP/05/3
M.M. Zhang, "Optimise the Cutoff Grade and NPV using Lane's Algorithm and a Dynamic Programming Method". February 2005.

BHPB/IMP/05/4
D. Allingham and R.H. Middleton, "Integrated Mine Planning with Mean Reverting Price", April 2005.

BHPB/IMP/05/5
G.C. Goodwin, M.M. Seron and B. Hennessy, "Further Analysis of the Guaranteed Performance Approach to Flexible Optimal Mine Planning", August 2005.

BHPB/IMP/05/6
G.C. Goodwin, M.M. Seron and B. Hennessy, "Adapting Guaranteed Cost Control to an MILP Solver", September 2005.

BHPB/IMP/05/7
G.C. Goodwin, M.M. Seron and B. Hennessy, "A Performance Trade Off with the MILP Formulation of Guaranteed Performance Control", September 2005.

HPB/IMP/05/8
G.C. Goodwin, M.M. Seron and B. Hennessy, "A Computational Strategy for Closed Loop Optimal Mine Planning Based on MILP", October 2005.

BHPB/IMP/05/9
M.M. Zhang, "A Preliminary Study of the Impact of Price Uncertainty to a Mine Plan", November 2005.

BHPB/OBOG/05/01
B.I. Godoy, "Progress Report on Bioleaching Modelling and Control", January 2005.

* International Co-Author

BHP/OBOG/05/2
B.I. Godoy, K. Lau and J.H. Braslavsky, "Optimisation-based Operator Guidance Progress Report", March 2005.

BHPB/OBOG/05/03
J.H. Braslavsky, K. Lau, and D. Allingham, "Optimisation-based Operator Guidance Progress Report", June 2005.

BHPB/OBOG/05/04
B.I. Godoy and J.H. Braslavsky, "Model Refinement and System Identification in Bioleaching Processes", August 2005.

BHPB/OBOG/05/05
J.H. Braslavsky and K. Lau, "Optimisation-based Operator Guidance Progress Report", September 2005.

BHPB/OBOG/05/06
Katrina Lau and Julio Braslavsky, "Sferics Project – Preliminary Report", October 2005.

BHPB/OBOG/05/07
D. Allingham, "Fault Detection Using Particle Filtering", November 2005.

BHPB/OBOG/05/08
K. Lau, D. Allingham, J.H. Braslavsky, and G.C. Goodwin, "Sferics Project Report 2, November 2005.

BHPB/OBOG/5/9
B.I. Godoy, J.H. Braslavsky, and K. Mahata, "Model Refinement and System Identification", December 2005.

Matrikon

Mat/NGMT/05/1
G.C. Goodwin and G.J. Adams, "A Priori Testing for Infeasibility", January 2005.

Mat/NGMT/05/2
A. Medioli and M.M. Seron, "MPC for Non-linear Systems Using Multiple Linear Models", January 2005.

Mat/NGMT/05/3
G.J. Adams, "Progress Report", February 2005.

Mat/NGMT/05/4
G.J. Adams, "Modification to the Active Set Method Implementation in the PACTmpc Toolbox", February 2005.

Mat/NGMT/05/5
G.J. Adams, "Closed-Loop Identification Software Development", March 2005.

Mat/NGMT/05/6
G.J. Adams, "PACTtune Autotuner Enhancements", April 2005.

Mat/NGMT/05/7
G.J. Adams, "Progress Report", May 2005.

Mat/NGMT/05/8
G.J. Adams, "Recent Additions to the PACTmpc Toolbox", June 2005.

Mat/NGMT/05/9
G.J. Adams, "Multi-Level Constraints and Active Set Issues", June 2005.

Mat/NGMT/05/10
G.J. Adams, "Progress Report", July 2005.

Mat/NGMT/05/11
G.J. Adams, "Evaluation of Benchmark Problems", September 2005.

Mat/NGMT/05/12
G.J. Adams, "PACTmpc Fixes", October 2005.

Mat/NGMT/05/13
G.J. Adams, "Implementing Multi-Level Constraints in PACTmpc", November 2005.

Mat/NGMT/05/14
G.J. Adams, "Progress Report", November 2005.

Mat/NGMT/05/15
G.J. Adams, "Identification Software Notes", December 2005.

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Performance Indicators Report

(P.1) Research Training

Description	2003 Actual	2004 Actual	2005 Actual	Details of 2005 Outcomes	2005 Target	03-07 Target
Refereed International Journal and Conference Publications	62	61	62	International Journal Publications (see page 37) International Conference Publications (see page 39)	40	200
Patents	–	–	1	See page 36		3
Major Presentations (Keynote etc.)	14	10	5	See Plenary Addresses (see page 36)	1	5
Science Citation counts for CDSC investigators	301	393	432	Search performed on ISI Web of Science, for all Centre Programme Leaders and Deputy Leaders. Numbers are external citations only to this group	200	1000

(P.2) Research Training and Professional Education

Description	2003 Actual	2004 Actual	2005 Actual	Details of 2005 Outcomes	2005 Target	03-07 Target
Recruit 25 Postgraduate Students	6	5	4	RHD commencements in 2005 (see page 5): Milan Derpich, Kate Lee, Christian Lovaas, Iskandar Mahmoud	5	25
Completed Research Higher Degrees	4	7	8	RHDs awarded in 2005 (see page 5): Sam Behrens, Petra Graham, Jun Ning, Daniel Quevedo, Osvaldo Rojas, Arief Syaichu-Rohman, Benjamin Vautier, Trent Yeend	4	20
Supervise 1st Class Honours students	8	4	12	**Benjamin Roberts** – "Design of SMPS with reduced EMI output" (Welsh) **Tyrone Crisp** – "Corners in graph algebras", (Szymanski) **James Foster** – "Quantum odd-dimensional balls from quantum double suspensions" (Szymanski) **Ruth Gibbs** – "Construction of a piezoelectrically actuated miniature swimming vehicle" (Moheimani) **Kenny Hong** – "NUbots: Enhancement of vision processing and debugging software for Robocup soccer" (Middleton) **Jason Kulk** – "Robocup rescue robot" (Middleton) **Steven Nicklin** – "Object recognition on robotic soccer" (Middleton) **Peter Lewin** – "Cuntz-Krieger families and Exel-Laca families", (A. Sims and Raeburn) **Alexander Sabella** – "Design of a secure communications system for CSIRO's intelligent agent network" (Moheimani) **Sarah Thomas (QUT)** – " Bayesian approaches for zero-inflated data" (Mengersen) **Melanie Watson** – "Developing classification rules to detect absence epilepsy in children" (Gerlach) **Natasha Weaver** – "An aperiodic 2-graph" (Pask and Raeburn)	6	30
Professional Courses run	0	1	3	• Constrained Control and Estimation – February • Constrained Control and Estimation – 26-30 September in Argentina • Bayes for Beginners and Bayesian QTL Analysis, Adelaide	4	5

Senior undergraduate and postgraduate courses taught by Centre investigators in the area of complex systems	4	4	7	• ELEC4400 Automatic Control (De Doná) • ELEC4410 Control Systems Design Management (Welsh/Braslavsky) • ELEC4210 Electronics Design (Middleton) • STAT3120 Bayesian Statistics (Gerlach) • STAT3130 Financial Time Series (Gerlach) • Integration and Fourier Analysis – Honours (Raeburn) • Symbolic Dynamics – Honours (Pask)	4	20
Interactive Learning Laboratories developed	3	3	2	• Laboratory XI – Quantization of Music I (Effect of Noise Shaping Feedback) • Laboratory XII – Quantization of Music II (Bode Sensitivity Integrals)	2	4

(P.3) International, National and Regional Links and Networks

Description	2003 Actual	2004 Actual	2005 Actual	Details of 2005 Outcomes	2005 Target	03-07 Target
International Research Visitors	19	19	14	See page 7	10	50
Papers with international co-authors	14	10	29	See page 36	20	100
National and International Workshop organisation	4	5	4	See page 9	5	25
Visits to Overseas Labs	17	20	14	**Fleming** – Department of Electrical Engineering, University of Washington, Seattle **Mengersen** – University of Paris and CREST, France, (December) **Middleton** – University of Michigan, (May); Maynooth Institute, Ireland (sabbatical August-January 2006); Lund Institute of Technology, (September), Chalmers University, (September) **Moheimani** –Department of Mechanical Engineering, University of California Berkeley, U.S.A.; Department of Electrical Engineering, University of British Columbia, Canada; Department of Mechanical and Process Engineering, ETH, Switzerland **Raeburn** – University of Colorado, USA (June and December); Dartmouth College, UK; University of Oslo, Norway **Yeend** – University of Iowa, USA	10	50

(P.4) End-user Links

Description	2003 Actual	2004 Actual	2005 Actual	Details of 2005 Outcomes	2005 Target	03-07 Target
Postgraduate Students involved in industrial projects (New students only)	–	7	1	**B. Hennessey** – BHP-Billiton Innovation	5	10
Visits by Centre Researchers to Industry	7	12	17	**Adams** – Matrikon (4) **Allingham** – BHP-Billiton Innovation (2) **Braslavsky** – BHP-Billiton Innovation (4) **Goodwin** – Matrikon (1); BHP-Billiton Innovation (2) **Lau** – BHP-Billiton Innovation (2) **Middleton** – BHP-Billiton Innovation (2)	5	25

(P.5) Organisational Support

Description	2003 Actual	2004 Actual	2005 Actual	Details of 2005 Outcomes	2005 Target	03-07 Target
Annual cash contributions from collaborating organisations	$400K	$475K	$726,912K	BHP-Billiton Innovation: $100,000 Matrikon: $75,000 The University of Newcastle: $307,520 NSW Department of State and Regional Development: $222,792 Queensland University of Technology: $21,600 (to QUT node)	$450K	$2250K
In-kind contributions from collaborating Organisations	$1,745,573K	$2,818,526K	$2,817,964K	The University of Newcastle: $2,235,354 Queensland University of Technology: $294,910 Matrikon: $142,600 BHP-Billiton Innovation: $145,100	$1.5M	$7.5M

(P.6) Governance

Description	2003 Actual	2004 Actual	2005 Actual	Details of 2005 Outcomes	2005 Target	03-07 Target
Advisory Board	1	1	1	Advisory Board Meeting held on 8 April 2005 (see page 10)	1	5

(P.7) National Benefit

Description	2003 Actual	2004 Actual	2005 Actual	Details of 2005 Outcomes	2005 Target	03-07 Target
Student Placements in other organisations	5	7	6	**Sam Behrens**, CSIRO, Newcastle **Petra Graham**, Health Informatics Group, CSIRO, Sydney **Jun Ning**, University of Sydney **Arief Syaichu-Rohman**, Bandung Institute of Technology, Malaysia **Osvaldo Rojas**, School of Electrical Engineering and Industrial Chemistry, University of New South Wales **Juan Yuz**, Departamento de Electrónica Universidad Técnica Federico Santa María, Valparaiso, Chile	2	10
Case Studies of Benefits				CDSC has jointly, with Engineers Australia (NCACI and Process Control Society), Rio Tinto and CSSIP, financially sponsored a study: "Achieving the Benefits of Improved Control in Australian Process and Manufacturing Industries". This study has been completed, and the report is expected to be released early in 2006.		
Industry Technical Reports	9	23	38	See page 40	5	25

Statement of Income and Expenditure for the Year Ended 31st December 2005

Account Name	Central Accounts (combined)	Control System Design	Signal Processing	Process Control and Optimiation	Mechatronics	Mathematical Systems Theory	Baysian Learning (UoN)	Bayesian Learning (QUT)	Total
Account Number	P513–1438, 1480, 1454, 1404, 5016, 5019, 5022	P513–1439	P513–1440	P513–1441, 1417, 1418, 1455, 1474, 1475, 1476	P513–1442	P724–1423, P724–0008	P724–1424	190751–0013 190751–0889	
Income									
2004 allocation b/f	31,000	85,397	219,784	256,919	177,630	116,220	180,785	–	1,067,735
ARC 05 grant	70,820	410,000	196,000	552,000	258,000	132,000	126,000	–	1,744,820
Other income	210,765	–	–	-31,595	–	–	–	–	179,170
The University of Newcastle support	262,500	–	–	–	–	45,020	–	–	307,520
NSW Dept State and Regional Dev	222,792	–	–	–	–	–	–	–	222,792
QUT Support	–	–	–	–	–	–	–	21,600	21,600
Total Income	**797,877**	**495,397**	**415,784**	**777,324**	**435,630**	**293,240**	**306,785**	**21,600**	**3,543,637**
Salary Expenditure									
Salaries (Academic)	193,943	228,123	57,089	243,677	132,551	76,132	80,382	120,000	1,131,897
Salaries (General)	6,736	24,597	–	35,809	4,246	–	–	–	71,388
Salaries on-costs	98,547	99,237	21,124	135,145	36,338	22,765	36,329	–	449,485
Scholarships/Student Support	15,500	56,581	–	34,691	10,793	28,595	-17	–	146,143
Total Salary and Related Costs	**314,726**	**408,538**	**78,213**	**449,322**	**183,928**	**127,492**	**116,694**	**120,000**	**1,798,913**
Non–salary Expenditure									
Consumables	20,212	2,398	2,873	4,846	11,634	-5,000	-762	–	36,201
Services	895	–	–	-4,425	239		-5,000	–	-8,291
Travel	24,848	42,177	-462	30,529	26,007	3,565	-25,709	–	100,955
Repairs and maintenance	529	–	–	–	13,566	–	–	–	14,095
Utilities	–	–	–	10,000	1,010	–	–	–	11,010
Equipment	12,660	–	–	20,000	7,215	770	–5,000	–	35,645
Others	–	–	–	–	–	-5,000	–	–	(5,000)
Shared Research Grant payment	68,000	–	–	–	–	–	52,000	(120,000)	–
Visitor	21,729	3,235	–	–	–	–	–	–	24,964
Total Non–Salary Expenditure	**148,873**	**47,810**	**2,411**	**60,950**	**59,671**	**-5,665**	**15,529**	**-120,000**	**209,579**
Total Expenditures	**463,599**	**456,348**	**80,624**	**510,272**	**243,599**	**121,827**	**132,223**	**–**	**2,008,492**
Balances as at 31/12/2005	**334,278**	**39,049**	**335,160**	**267,052**	**192,031**	**171,413**	**174,562**	**21,600**	**1,535,145**

Note: $120K allocated to QUT node, the amount is fully spent on academic and general salaries.
Note: Estimated liabilities due to salary increases and post 2007 salary contracts approximately $M1.

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