CDSC

ARC Centre for Complex Dynamic Systems and Control

Annual Report 2004

The University of Newcastle
AUSTRALIA

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Director's Report

2004 has been a year of consolidation, focus and significant progress across a number of fronts for the Research Centre. We have been able to finalise contracts, financial arrangements and other administrative matters throughout the year, and we owe a great debt to many for their help with this, including our Executive Officer, Dianne Piefke, other administrative staff at the University, and also our industry partners. This has allowed us to improve our focus on research projects and build momentum in these areas.

There have been a number of significant outcomes and recognitions in 2004. We have tried to capture some of the main events in the 'Highlights' section of this report which I commend to your attention. I must confess to being pleased and proud at the range and quality of the highlights mentioned across all our research programs.

There have been several shifts in researcher positions through the year. We were sad to hear that Kerrie Mengersen has left Newcastle, but very pleased that we have been able to continue collaborating with Kerrie by forming a CDSC node at Queensland University of Technology. Unfortunately for us also, Will Heath left early in the year to take up a regular academic position at UMIST in the UK. We were also sorry to hear at the end of 2004 that Karsten Weihe, who had joined as project leader for our Integrated Mine Planning project with BHP-Billiton is not able to continue in this role which will be picked up by others in 2005. We wish Will and Karsten all the best in their future roles.

On the other hand, we are delighted to have a range of new appointments to Research Fellow positions in 2004, and we extend a warm welcome to Greg Adams, Andrew Fleming, Zahirul Hoque, Katrina Lau, Kaushik Mahata and Ross McVinish. We look forward to working with them and others 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
Professor Kerrie Mengersen (QUT)
Richard Gerlach
Associate Professor Reza Moheimani
Professor Iain Raeburn

Chief Investigators
Dr Julio Braslavsky
Dr Jose De Doná
Dr Richard Gerlach
Dr William Heath (until March 2004)
Dr Maria Seron
Associate Professor Brailey Sims

Industry Partner Investigators
Dr Salvatore (Sam) Crisafulli (Matrikon)
Dr Mera Menabde (BHP-Billiton Innovation)
Mr Chris Shelton (BHP-Billiton Innovation)
Mr Peter M Stone (BHP-Billiton Innovation)
Mr Richard Thomas (Matrikon)
Dr Robert O Watts (BHP-Billiton Innovation)

Associate Investigators
Associate Professor Robert E Betz
Mr Tom Honeyands
Dr Robert King
Dr Claus Mueller
Dr Darfiana Nur
Dr David Pask
Dr Jacqui Ramagge
Mr Paul Rippon
Dr Wojciech Szymanski
Mr Richard Thomas
Mr Steven Vandenberg

Academic Research Staff
Dr Greg Adams
Dr Andrew Fleming
Dr Richard Gerlach
Dr Zahirul Hoque
Dr Katrina Lau
Dr Ross McVinish (QUT)
Dr Kaushik Mahata
Dr Aidan Sims
Dr Ian Wood (QUT)
Dr Mei Mei Zhang

Engineering Staff
Mr Adrian Bastiani
Mr Frank Sobora
Mr Michael Santarelli

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

Postgraduate Research Students

Juan Carlos Agüero
"Novel algorithms on system identification"
Supervisor: G C Goodwin
Co-Supervisor: J A De Doná
Degree: PhD

Stephen Allen
"Aspects of k-graph C-algebras"*
Supervisor: D Pask
Co-Supervisor: I Raeburn
Degree: PhD

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

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

Simon Dodds (Graduated 2004)
"Online monitoring of quality in food extrusion: A spectroscopic approach"
Supervisor: W P Heath
Co-Supervisor: G C Goodwin
Degree: PhD

Andrew Fleming (Graduated 2004)
"Synthesis and implementation of sensor-less shunt controllers for piezoelectric and electromagnetic vibration control"
Supervisor: S O R Moheimani
Co-Supervisor: M Fu
Degree: PhD

Angus Giles
"Automatic control of extruder"
Supervisor: R H Middleton
Co-Supervisor: L Wang
Degree: PhD

Petra Graham
"Statistical methods for assessing and improving quality in hospitals"
Supervisor: K Mengersen
Degree: PhD

Boris Godoy
"Control of biologically enhanced heap leaching"
Supervisor: J H Braslavsky
Co-Supervisor: R H Middleton
Degree: PhD

Hernan Haimovich
"Nonlinear constrained control"
Supervisor: G C Goodwin
Co-Supervisor: M M Seron
Degree: PhD

Bryan Hennessy
"Performance limitations in constrained control"
Supervisor G C Goodwin
Co-Supervisor: M M Seron
Degree: PhD

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: M M Seron
Co-Supervisor: R H Middleton
Degree: ME

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

Zead Mustafa
"Generalised metric spaces"
Supervisor: B Sims
Co-Supervisor: I Raeburn
Degree: PhD

Jun Ning (Submitted November 2004)
"Serially concatenated codes for continuous phase modulation"
Supervisor: M Fu
Degree: PhD

Tristan Perez (Graduated 2004)
"Multivariable control applications"
Supervisor: G C Goodwin
Co-Supervisor: S R Weller
Degree: PhD

Daniel Quevedo
"Quantized control over networked communication systems"
Supervisor: G C Goodwin
Co-Supervisor: J A De Doná
Degree: PhD

Alejandro Rojas
"Dynamics of coupled oscillators systems"
Supervisor: R H Middleton
Co-Supervisor: J A De Doná
Degree: ME

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

Elizabeth Stojanovski
"Multivariate methods in the health sciences"
Supervisor: K Mengersen
Degree: PhD

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

Ian Searston
"Fixed-point theory in spaces of non-positive curvature"
Supervisor: B Sims
Co-Supervisor: G Willis
Degree: PhD

Aidan Sims (Graduated 2004)
"Relative higher-rank graph algebras"
Supervisor: I Raeburn
Co-Supervisor: W Szymanski
Degree: PhD

Mark Smith
"Ultraproduct methods in 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
"Graph algebras and quantum deformations"
Supervisor: I Raeburn
Co-Supervisor: W Szymanski
Degree: PhD

Ben Vautier
"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
"Parsimonious information structures in real time signal processing"
Supervisor: G C Goodwin
Co-Supervisor: R H Middleton
Degree: ME

James Welsh (Graduated 2004)
"Ill-conditioned inverse problems arising in closed loop system identification"
Supervisor: G C Goodwin
Co-Supervisor: M Fu
Degree: PhD

Darren Woodhouse (Graduated 2004)
"An evolution in earthing system testing: Refinement of earthing system current injection testing and its analysis with emphasis on earth potential rise estimation"
Supervisor: R H Middleton
Co-Supervisor: B M Ninness
Degree: PhD

Trent Yeend
"Higher-rank topological graphs"
Supervisor: I Raeburn
Co-Supervisor: D Pask
Degree: PhD

Juan Yuz
"Fundamental limitations in estimation and control"
Supervisor: G C Goodwin
Degree: PhD

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

Advisory Board

The Advisory Board meets once per year to offer advice on matters of concern to the Centre. The 2004 membership of the Advisory Board was:

Professor B D O Anderson
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
Department of Electrical and Computer Systems Engineering, Monash University, Victoria

Professor R J MacDonald
Deputy Vice-Chancellor (Research), the University of Newcastle, Callaghan, NSW

Professor I M Y Mareels
Department of Electrical and Electronic Engineering, University of 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

Professor I R Petersen
Department of Electrical Engineering, University College, University of New South Wales, Australian Defence Force Academy, Canberra, ACT

Dr S J Smith
TUNRA Limited, Callaghan, NSW

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

Review Committee

A Review Committee (made up from a representative of each research partner, CDSC Program Leaders and Deputy Program Leaders) meets quarterly to maintain contacts between industry and the Centre and review program budgets, etc. The industrial representatives are:

Peter M Stone
BHP-Billiton Innovations, Melbourne, Victoria

Tom A Honeyands
BHP Billiton, Newcastle Technology Centre, Newcastle, NSW

Richard Thomas
Matrikon, Mayfield, NSW

Visitors

Professor David Balding
July
Professor of Statistical Genetics, Imperial College, London

Distinguished Professor Cathy Chen
July
Feng Chia University, Taiwan

Dr Steven Duffull
June
University of Queensland, Brisbane

Ms Cindy Farthing
January – May
Department of Mathematics, University of Iowa, USA

Professor Arie Feuer
July – September
Department of Electrical Engineering, Technion – Israel Institute of Technology, Israel

Professor James Freudenberg
October
Department of Electrical Engineering and Computer Science, University of Michigan, USA

Professor Hugues Garnier
September 2003 – August 2004
Centre de Recherche en Automatique de Nancy, Université Henri Poincaré, Nancy, France

Dr Jeong Hee Hong
July – August
Department of Applied Mathematics, Korea Maritime University, Busan, South Korea

Professor Arthur Jutan
June – August
Department of Chemical and Biochemical Engineering, The University of Western Ontario, London, Ontario, Canada

Professor Art Kirk
February – March
Department of Mathematics, University of Iowa, USA

Professor Bengt Lennartson
September 2003 – April 2004
Control and Automation Laboratory, Department of Signal and Systems, Chalmers University of Technology, Sweden

Dr Bob Murison
September
University of New England, Armidale, NSW

Mr Dominik Niederberger
September – October
Department of Electrical Engineering, ETH, Zurich, Switzerland

Ms Katherine Peterson
August – December
Department of Mechanical Engineering, The University of Michigan, Ann Arbor, USA

Professor Christian Robert
Department of Mathematics, University Paris Dauphine, INSEE, Paris, France

Professor Mikael Rordam
November
Mathematics Institute, University of Southern Denmark

Ms Anna Rosén
August 2003 – February 2004
Department of Electrical Engineering, Linkoping University, Sweden

Professor Judith Rousseau
November
Department of Statistics, University Paris Dauphine, INSEE, Paris, France

Professor Sirish Shah
February – April 2004
Department of Chemical and Material Engineering, University of Alberta, Edmonton, Canada

Dr Mike So
July
Hong Kong University of Science and Technology

Professor Hitoshi Takata
September
Department of Electrical and Electronics Engineering, Kagoshima University, Japan

Mr Henrik Tidefelt
August 2003 – February 2004
Department of Electrical Engineering, Linkoping University, Sweden

Dr Mark Tomforde
July – August
Department of Mathematics, University of Iowa, USA

Professor Peter Wellstead
November
Hamilton Institute, Maynooth, Ireland

Professor Kyung Sang Yoo
February 2003 – February 2004
Department of Electrical Engineering, Doowon Technical College, Korea

Professor Yufeng Zheng
August 2003 – February 2004
Department of Electrical and Electronic Engineering, The University of Melbourne, Australia

Modern Industrial Control

This three day short-course was held 4 – 6 May at the University.

Participants in the course were exposed to a broad range of theoretical and practical issues associated with industrial control systems. The key feature of the course was the hands-on sessions interspersed with the theory, where participants continually put into practice what was taught in lectures. These sessions were designed to address the issues of technical feasibility and economic justification of modern control in industry.

Members of CDSC who contributed to the short course were:

- Greg Adams
- Julio Braslavsky
- Jose De Doná
- Minyue Fu
- Graham Goodwin
- Rick Middleton
- Maria Seron

The remaining two presenters from the School of Electrical Engineering and Computer Science at the University of Newcastle, were:

- James Welsh
- Adrian Wills

Tutorial Workshop on Model Predictive Control

In conjunction with the 5th Asian Control Conference, this workshop was presented by Maria Seron and Jose De Doná from the Centre (with Liuping Wang and Andrew Eberhard from RMIT) in Melbourne on 20 July.

2004 IFAC Symposium on Mechatronic Systems

Jointly organised by the CDSC and Engineers Australia, approximately 130 participants from around the world attended this Symposium in Manly, Sydney, 5 – 8 September. Plenary speakers were:

- **Werner Dieterle**
  Robert Bosch GmbH
  "Mechatronic Systems: Industrial Applications and Modern Design Methodologies"
- **Hugh Durrant-Whyte**
  Australian Centre for Field Robotics (ACFR) The University of Sydney, Australia
  "Autonomous Navigation in Unstructured Environments"
- **Roberto Horowitz**
  Department of Mechanical Engineering, University of California at Berkeley
  "Dual-Stage Servo Systems and Vibration Compensation in Computer Hard Disk Drives"
- **Kouhei Ohnishi**
  Department of System Design Engineering, Keio University, Japan
  "Medical Mechatronics – An Application to Haptic Forceps"
- **Anna G Stefanopoulou**
  Mechanical Engineering Department, University of Michigan
  "Mechatronics in Fuel Cell Systems"
- **Herman M J R Soemers**
  Philips CFT Mass Products and Technologies and, University of Twente, Drebbel Institute for Mechatronics, The Netherlands
  "Mechatronics and Micro Systems"

Also, the following Semi-Plenary speakers presented exciting seminars:

- **Professor Roger Goodall**
  Department of Electronic and Electrical Engineering, Loughborough University, UK
  "Mechatronics in motion – some railway applications"
- **Professor Rolf Isermann**
  Institut fuer Automatisierungstechnik, Technische Universitaet Darmstadt, Germany
  "Model based control and diagnosis of automobiles with mechatronic actuation"
- **Professor Carl Knospe**
  Mechanical and Aerospace Engineering, University of Virginia, USA
  "Active magnetic bearings for machining applications"
- **Professor Hideki Hashimoto**
  Institute of Industrial Science, University of Tokyo, Japan
  "Robotics and intelligent space"
- **Professor Job van Amerongen**
  Cornelis J Drebbel Institute for Mechatronics, University of Twente, The Netherlands
  "Mechatronics education – 15 years of experience"
- **Professor Masayoshi Tomizuka**
  Mechanical Engineering, University of California, Berkeley, USA
  "Sensors in the engineering of modern mechatronic systems"

Nonlinear Control Methods and Tools: When and How to Use Them

This one-day professional development workshop was held at the University of Newcastle on 3 November. The purpose of the workshop was to present, in a tutorial fashion, a selection of recently developed user-friendly tools for nonlinear control design accessible to practising engineers. The tools for both finite and infinite dimensional (distributed) systems were illustrated by typical applications. The workshop was organised in three 90-minute lectures by Professors Kokotovic, Krstic and Mareels.

Professor Petar V Kokotovic
Founder and Director,
Center for Control Engineering and Computation
University of California, Santa Barbara, USA

Professor Miroslav Krstic
Vice-Chair,
Department of Mechanical and Aerospace Engineering
University of California, San Diego, USA

Professor Iven Mareels
Department of Electrical and Electronic Engineering
The University of Melbourne, Australia

Constrained Control and Estimation

This one week summer school was presented in Grenoble, France, by Graham Goodwin, Maria Seron and Jose De Doná with invited guest speaker David Mayne giving a presentation. There were approximately 100 attendees at the course. It is planned to run the same course in Newcastle in February 2005.

Bayesian Topics in the Tropics

The inaugural international meeting, "Bayesian Topics in the Tropics", was organised as a Program activity by Kerrie Mengersen, in collaboration with the Statistical Society of Australia and the Australasian Society for Bayesian Analysis. Approximately 40 people from four countries attended the three-day meeting on Stradbroke Island, Queensland.

Other short courses presented in 2004 by Bayesian Learning Program Leader, Kerrie Mengersen, were:

- **"Bayes for Beginners and Bayesian QTL Analysis"** (four days, Armidale, February)
- **"Bayesian Methods for Biometricians"** (two days, Canberra, June)
- **"Bayes for Beginners"** (one day, Brisbane, October)
- **"Data Analysis for Transport"** (one day, Brisbane, November)
- **"Bayes for Beginners"** (two days, Perth, December)

Seminars

Research students and staff from the University of Newcastle as well as Australian and international visitors participate in the Centre's seminar series. Seminars presented in 2004 are listed below.

20 January

Professor Michael Henson

Chemical Engineering Department, University of Massachusetts, USA

"Modelling the synchronisation of autonomously oscillating yeast cultures"

18 February

Professor Sirish L Shah

NSERC-Matrikon-ASRA Senior Industrial Research Chair, Department of Chemical and Materials Engineering, University of Alberta, Canada

"Process and Performance Monitoring"

19 February

Professor Tamer Basar

Professor G T Elizabeth

H Nearing Professor of Electrical and Computer Engineering, Coordinated Science Laboratory, University of Illinois at Urbana – Champion, Illinois, USA

"Resource Management pricing and congestion Control for high-speed networks"

19 February

Dr Shad Roundy

Department of Engineering, Australian National University, Canberra

"Energy scavenging for wireless sensor networks with a focus on vibration-to-electricity conversion"

25 February

Professor Sirish L Shah

NSERC-Matrikon-ASRA Senior Industrial Research Chair, Department of Chemical and Materials Engineering, University of Alberta, Canada

"Multivariate controller performance analysis: Methods, applications and challenges"

3 March

Professor Peter Young

Centre for Research on Environmental Systems and Statistics, University of Lancaster, UK

"Some thoughts on the identification, estimation and control of systems described by transfer function models"

16 March

Professor Bengt Lennartson

Department of Signals and Systems, Chalmers University of Technology, Sweden

"From PID to H-infinity control in a unified framework using the delta operator and LMIs"

7 April

Dr Kaushik Mahata

Centre for Complex Dynamic Systems and Control, the University of Newcastle

"On spectrum estimation using state covariances"

2 June

Professor Ian Petersen

School of Information Technology and Electrical Engineering, University of New South Wales at the Australian Defence Force Academy, Canberra, ACT

"Robust unobservability for uncertain linear systems with structured uncertainty"

17 August

Dr Ross McVinish

Faculty of Science and School of Mathematical Sciences, Queensland University of Technology

"Stochastic semilinear FDEs and Bayesian nonparametrics"

25 August

Dr Rogelio Lozano

CNRS Research Director, Laboratory Heudiasyc, University of Technology of Compiègne, France

"Robust prediction-based control for unstable delay systems"

10 September

Dr Roger Goodall

Electronic Systems and Control Research Group, Loughborough University, United Kingdom

"Controlling the dynamic characteristics of rail vehicles (concepts, opportunities and challenges)"

10 September

Professor Job van Amerongen

Department of Elecrical Engineering, University of Twente, The Netherlands

"Mechatronic design"

13 October

Professor Peter Gawthrop

Centre for Systems and Control, Department of Mechanical Engineering, University of Glasgow, UK

"Virtual actuators for model-based simulation and control"

11 November

Professor Peter Wellstead

SFI Research Professor, Hamilton Institute, NUI, Maynooth, Co. Kildare, Ireland

"Using classical control analysis to re-design internet transport control protocols"

24 November

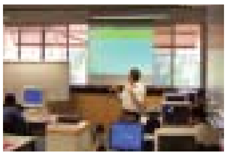
Professor Peter Wellstead

SFI Research Professor, Hamilton Institute, NUI, Maynooth, Co. Kildare, Ireland

"An informal introduction to systems biology"

Selected Highlights 2004

- In February, the Annual Summer Systems and Control Workshop (http://scrg.ee.unsw.edu.au/workshop04/wshp04.html) was held at the University of NSW. A range of talks on Communications and Control were held, including the key presentation by Tamer Basar of the University of Illinois at Urbana-Champaign.
- Iain Raeburn was invited as part of an NSF funded Regional Research Conference (http://www.math.uiowa.edu/faculty/cbms/cbms.html) to present a series of talks on "Graph Algebras: Operator Algebras We Can See" at the University of Iowa, from 31 May to 4 June. David Pask and Aidan Sims were also invited to make presentations at the conference.
- During May, we presented a week-long short course on Modern Industrial Control. This was again well attended, with much interest in the constrained control portions of the material.



- In May, Graham Goodwin travelled to Sweden where he was elected a Foreign Member of the Royal Swedish Academy of Science.
- On 10 May, Graham Goodwin presented the William Mong Distinguished Lecture in Engineering and Computer Science at the University of Hong Kong.
- In July, the NUbots travelled to Lisbon (Portugal) to compete in the World Robocup Soccer, Sony 4 Legged League. They achieved third place in a tough competition won by the German team.

- In July, Reza Moheimani was invited to give a keynote address at the 2004 International Congress on Mechatronics (http://www.mechatronics.cz/mech2k4/) held in Prague.

- During September, Reza Moheimani chaired the third International Federation on Automatic Control (IFAC) Symposium on Mechatronic Systems (http://mechatronics2004.newcastle.edu.au/mech2004/). This is a high quality biannual international meeting, which attracted a number of internationally renowned researchers in the area.

- In September/October, Graham Goodwin visited the University Tecnica Federico Santa Maria in Chile where he was appointed a Distinguished Professor.
- The Inaugural "Bayesian Topics in the Tropics" international workshop, organised by the Australian Association for Bayesian Analysis (http://www.maths.qut.edu.au/asba/) was held at Stradbroke Island, October 2004. Kerrie Mengersen was part of the team organising this workshop.
- Clair Alsten, PhD student at Newcastle, won the SSAI (Statistical Society of Australia Inc) NSW Postgraduate Award, 2004, for her presentation on "Bayesian mixture modelling of spatial images". This award is given to the best presentation from a postgraduate student enrolled at a NSW university, at a special competition held in Sydney.
- Graham Goodwin has been asked to join the Selection Advisory Committee for the Australian Research Council's (ARC) Centres of Excellence Program.
- Maria Seron, Jose De Doná and Graham Goodwin presented a one week course on Constrained Control and Estimation in Grenoble, France 13–17 September. There were 93 participants from many countries and good feedback was obtained from the participants.
- ProcessACT won the Control Engineering Magazine's Editors Choice Award in the category of Process and Advanced Control. This is a significant accolade for ProcessACT, originally conceived as UNAC by Professor Graham Goodwin as part of an early research centre, CICS. Please see http://www.manufacturing.net/ctl/article/CA491813 for details.
- In December 2004, Minyue Fu was presented with his award of Fellow of the IEEE for "Contributions to Robust Control and Signal Estimation".
- Rick Middleton was awarded the M A Sargent Medal for 2004. This is a national award made by the Electrical College of Engineers Australia for outstanding contributions to the science or practice of Electrical Engineering. (see http://www.ieaust.org.au/about_us/colleges/electrical/)
- Ian Wood, Research Associate affiliated with the Bayesian Learning Program at QUT, won the Best Poster Award at the BioInfo Summer Workshop in Canberra, for his work on the statistical aspects of popular optimisation software programs.
- Robert Denham, PhD student under the supervision of CI Mengersen, won the Best Student Presentation prize at the International Society for Bayesian Analysis Conference in Chile, for his work on methods for elicitation of expert opinion as priors for Bayesian modelling.

[1] Control Engineering Magazine is one of North America's leading magazines in the field of control engineering.

A. Control System Design

Program Leader: Graham Goodwin
Deputy Leader: Maria Seron

Program Goals: Control System Design is a mature discipline. Surprisingly, however, the existing methodologies tend to be limited to relative standard problems – eg linear, unconstrained and with centralised architectures. As soon as one departs from these settings one soon finds oneself faced with severe difficulties.

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: Osvaldo Rojas, Graham Goodwin, Maria Seron, Juan Yuz (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 Anti-Windup and Model Predictive Control

Researchers: Rick Middleton, Arief Syaichu-Rohman (Student)

Work has continued in this area where we examine optimisation approaches to designing controllers for input constrained systems from both an anti-windup and an MPC perspective. We have extended computational studies of our fixed point iteration algorithms, which allow implementation of MPC controllers via a large number of very simple iterations. Some of the tests compare reasonably in terms of overall CPU requirements with the commonly used active set or interior point methods.

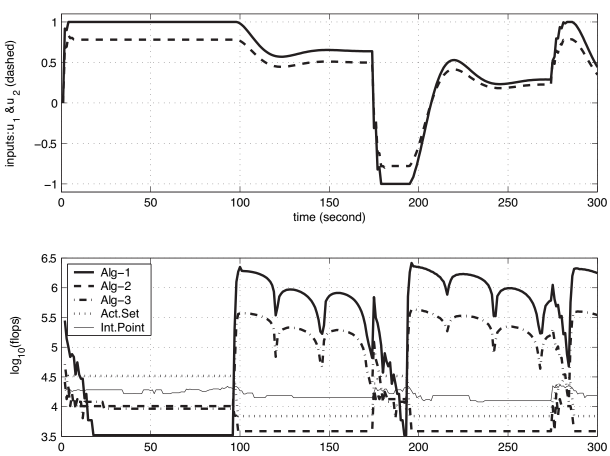


Figure 1

In addition, we have also examined some multirate algorithms, whereby a finite number of solution iterations may be implemented. Because of the simple structure of these algorithms, they permit, in a straightforward manner, an LMI based stability test. In addition, in some of the cases examined, for even a small number of iterations (eg 3 – see below), the performance is almost indistinguishable from that of the exact solution to the MPC problem.

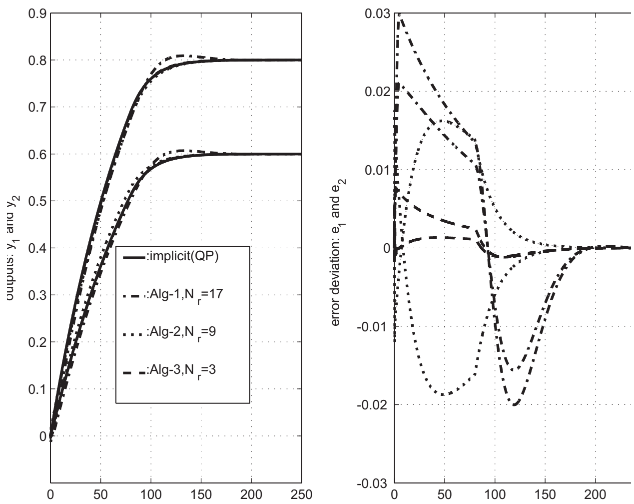


Figure 2

A.3 Limiting Results in Constrained Control

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

We have studied the problem of control of constrained linear systems when fast sampling rates are utilised. 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 discretisation now plays a 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 normalised 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.4 Vibration Control of Flexible Structures

Researchers: Reza Moheimani, Graham Goodwin, Katrina Lau

We have proposed a novel method for controlling vibrations within a resonant structure equipped with piezoelectric transducers. The scheme uses a parallel connection of modulated and demodulated controller, each designed to damp the transient oscillation corresponding to a single mode. This technique allows multiple modes to be controlled with a single actuator. Note that this project is also linked to project 4.1. We have also tested the method on a real beam.

A.5 Unified Sampled Data Approach to H∞ Using Delta Operators

Researchers: Bengt Lennartson (Chalmers, Sweden), Rick Middleton

In this research project, we examine a unified framework for H^∞ control, where discrete, continuous, sampled data, and discrete event systems are considered jointly. In this framework, a number of problems such as reduced order optimal control can be considered via linear or bi-linear matrix inequalities. In this framework, there are a number of numerical issues that arise, particularly with fact sampling, whereby the traditional shift operator based formulations lead to poor conditioning and inaccurate solutions to the LMIs or BMIs. A careful study of solution algorithms reveals a delta operator based solution technique that is applicable over a very wide range of sampling periods and systems, without giving rise to numerical problems.

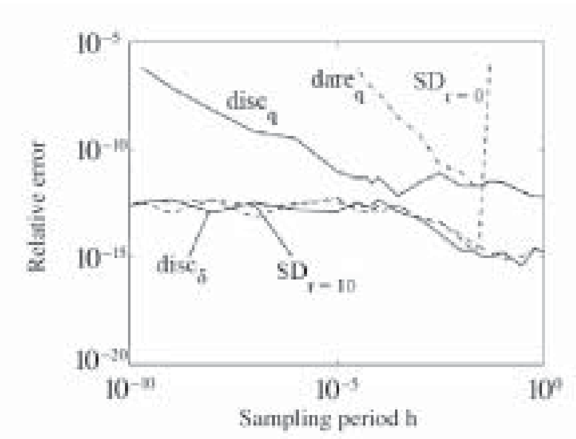


Figure 3

A.6 Cross Directional Control

Researchers: Osvaldo Rojas, Tino Domanti (IAS), Graham Goodwin

Earlier reports have detailed our investigations into Cross Directional Control. We have continued these studies with particular reference to several industrial control problems that exhibit strong cross directional effects. Industrial implementation of one of the designs is currently in progress.

A.7 Performance Limitations in Modulated Systems

Researchers: Graham Goodwin, Katrina Lau

Modulated and demodulated control systems appear in many applications. A particular example is a micro-gyroscope which is the subject of a major investigation by Professor Robert M'Closky at UCLA. This project has motivated us to study the performance limitations due to the use of modulation in control systems.

In particular, it is well known that the poles, zeros and delay of a system play an important role in determining the associated feedback performance limitations. In this project, we have developed an approximate transfer function for a modulated and demodulated system of a particular form. We have then used this to analyse the behaviour of the poles, zeros, and delay of this transfer function when the modulation frequency is varied. Some implications of these results to practical problems have also been studied.

The results on poles and zeros of modulated systems have allowed us to study the feedback performance limitations for modulated and demodulated control systems whose base systems have nonminimum phase (NMP) zeros or unstable poles. We have derived a transfer function for the modulated system and then shown how the poles and zeros of this function are related to those of the base system. We have then analysed the behaviour of the poles and zeros, when the modulation frequency is varied. Bode and Poisson Integral constraints for the modulated systems are then considered. The effect of a base system delay has been addressed.

A.8 Generalised Hold Functions for Fast Sampling Rates

Researchers: Juan Yuz (Student), Graham Goodwin, Hugues Garnier (Nancy, France)

It is well known the generalised 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 generalised 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 generalised 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.9 Performance Limitations Arising from Decentralised Architectures in Control

Researchers: Mario Salgado (Valparaiso, Chile), Eduardo Silva (Valparaiso, Chile), Graham Goodwin

Predominantly, control theory deals with centralised (unrestricted) architectures. However, in practice, decentralised 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 decentralised architecture. These fundamental limitations can guide the design of decentralised 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 decentralised control architectures.

A.10 Fundamental Constraints in Control Over SNR Limited Channels

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

Work on the quantification of control constraints in systems with feedback over a communication link has progressed actively during 2004. The scenario under study is the problem of stabilisation of an unstable plant by feedback over an Additive White Gaussian Noise (AWGN) channel with a constraint on the channel input signal-to-noise ratio (SNR).

The proposed scenario intentionally disregards the effect of signal coding and decoding schemes, and nonlinearities such as quantisers, common in other studies of control over communication links. In return, our problem formulation translates directly into a familiar optimal H2 framework, with the benefit of a comparatively simpler derivation of the minimal conditions for stabilisability. Such conditions are expressed as bounds on the lowest channel SNR, and are shown to be equivalent to those derived, for example, by Nair, Evans, and other researchers.

Building upon our earlier results, work during 2004 has extended the approach to unstable plants with time-delays, and AWGN channels with bandwidth constraints, both in the continuous and discrete-time domains. Time delay and bandwidth constraints are arguably two of the most significant control constraints imposed by feedback over a communication link. Our work on unstable plants with a time delay has produced analytical bounds for the lowest channel SNR compatible with closed-loop stability. These bounds show that a time delay can exponentially worsen the requirements on SNR with respect to those for a delay-free unstable system. Current work in this area includes the use of Pade Approximants to numerically quantify the simultaneous effect of unstable poles, non-minimum phase zeros, and time-delay on SNR bounds.

Our work on AWGN channels with bandwidth constraints aims to capture more realistic situations within the proposed SNR constrained framework. Initial work has quantified the additional penalties imposed by bandwidth limitations as closed-form expressions for the required SNR compatible with closed-loop stability. Current work in this area includes the extension of these expressions to fading channel models, of greater interest than AWGN channel models in wireless communication scenarios.

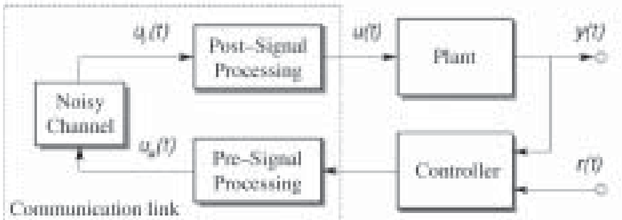


Figure 4: General framework for feedback control over a communication link (remote actuation)

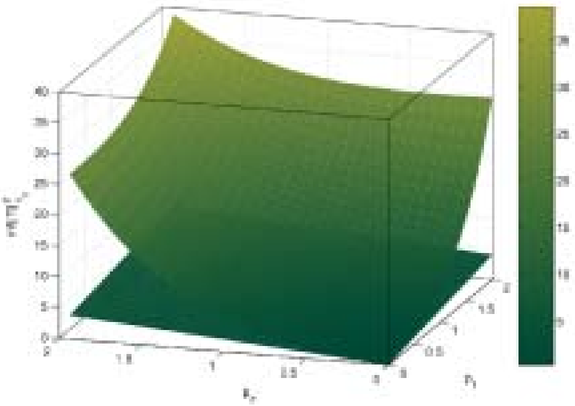


Figure 5: Lowest SNR bound for stabilisability of a plant with two real unstable poles and time delay: (1) unit time delay (upper manifold), (2) no delay (lower plane)

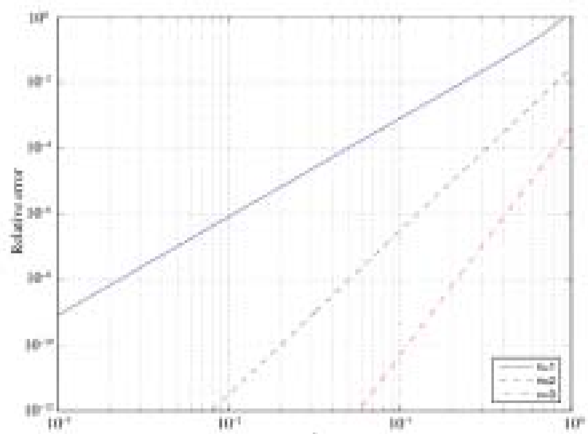


Figure 6: Relative errors in computing SNR bounds for feedback stabilisability of a time-delayed plant via Pade Approximants of orders 1, 2 and 3

A.11 Duality of Constrained Control and Estimation

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

This project was described in some detail in our 2003 report. However, the associated paper has now been accepted for publication so it seems appropriate to briefly review the results.

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 optimisation 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 Meuller have extended the result to cover noise constraints.

A.12 Development of Virtual Laboratories for Control System Design

Researchers: Graham Goodwin, Adrian Bastiani, Frank Sobora, Michael Santarelli, Peter Wellstead (Maynooth, Ireland), Osvaldo Rojas

This project has been ongoing 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 2005.

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 – Quantisation of Music I (Effect of Noise Shaping Feedback)
- Laboratory XII – Quantisation of Music II (Bode Sensitivity Integrals)

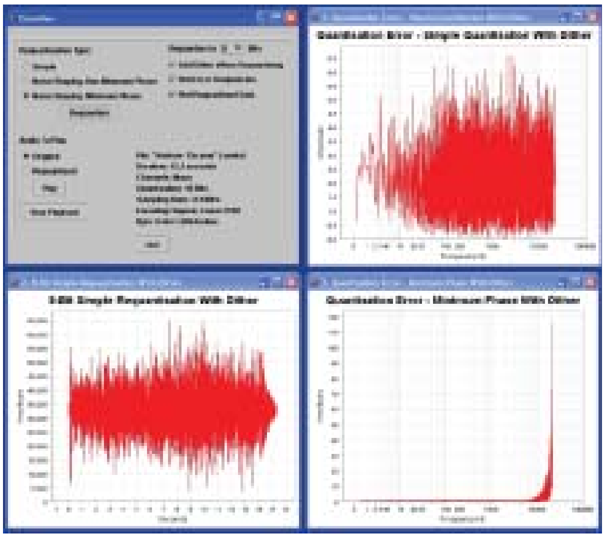


Figure 7: Audio Laboratory requantisation

A.13 Integral Quadratic Constraint Approach to Robustness Analysis

Researchers: Minyue Fu, Soura Dasgupta (Iowa, USA), Y.C. Soh (Nanyang, Singapore)

Integral quadratic constraints (IQC) arise in many optimal and/or robust control problems. The IQC approach can be viewed as a generalisation of the classical multiplier approach in the absolute stability theory. In this paper, we study the relationship between the two approaches for robust stability analysis. Using a slightly modified multiplier approach, we show that the existence of an IQC is equivalent to the existence of a multiplier in most known cases. It is hoped that this result provides some new insight into both approaches and makes them more useful in robust control applications.

A.14 Computational Complexity of Static Output Feedback Design

Researcher: Minyue Fu

This project is motivated by the following long-standing problem of static output feedback stabilisation (SOFS): Given a linear time-invariant system, determine if it is stabilisable via static output feedback. This is arguably one of the most fundamental yet unsolved control problems. In this project, we study a related problem, the problem of pole placement via static output feedback for linear time-invariant systems. We show that this problem is NP-hard. This result strengthens the belief that static output feedback design problems in general have intractable computational complexities.

A.15 Robustness Analysis and Control Design for Nonlinear Systems

Researchers: Minyue Fu, Daniel Coutinho (Brazil)

This project deals with the problem of robustness analysis and control design for a class of nonlinear discrete-time systems with constant uncertain parameters. For the analysis problem we use a polynomial Lyapunov function and propose an LMI optimisation approach to maximising an estimate of the domain of attraction. We then extend this approach to the synthesis problem by considering parameter-dependent Lyapunov functions and nonlinear multipliers.

A.16 Geometric Framework for Quantised Control Systems

Researchers: Hernan Haimovich (Student), Maria Seron

Systems involving quantisation arise in many areas of engineering, especially when digital implementations are involved. In recent years, especially motivated by control of systems over communication networks, a novel approach to quantised control systems has emerged that regards quantisation as unavoidable and thus essential, and interprets a quantiser as an information coder. This approach leads to new and important questions regarding control systems, such as minimum data rates to achieve stability, different stability notions (since asymptotic stability may not be possible in some settings), minimum density (coarse) quantisers and the interrelationship between control and information theory, just to name a few.

Our project has focused on the question of quadratic stabilisation of discrete-time systems with coarse quantisers. Our key contribution has been to provide a geometric framework for the analysis and design of quadratically stabilising quantisers which leads to a rather intuitive understanding of minimum density quantisers. Specifically, we have explored the notion of quantisation density from a state-space standpoint for state quantisers of a special form, which we call parallel-hyperplane quantisers. Such quantisers arise from the composition of a scalar product (between the state and a direction vector) and a scalar quantiser. Using geometric concepts, we have developed an alternative method for constructing quadratically stabilising quantisers of the afore-mentioned type. Our approach is based on analysing the partition induced on the state-space by the quantiser. We have utilised the developed geometric framework to design static output feedback strategies with a minimum density quantiser and to recover an important result by Elia and Mitter (2001) on minimum quantisation density for single-input systems. The geometric framework may also be useful in finding alternative ways of generalising the latter result to multiple-input systems.

A.17 Backlash Compensation Using Receding Horizon Control

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

Backlash is a common nonlinearity that limits control performance in many industrial applications, notably mechanical and hydraulic systems. Yet, according to a survey paper published in 2002, few control innovations aimed at this problem have been presented since the early strategies based on describing function analysis. In this project we have considered backlash compensation under the receding horizon control (RHC) framework for stable linear system under control rate constraints. By modelling the backlash nonlinearity as a piecewise-affine system with three regions, the receding horizon optimal control problem with horizon N for these systems involves the solution of 3N quadratic programs (QP). A key issue is then the inherent computational complexity of controller synthesis and analysis. To circumvent this complexity issue, we have proposed to approximate the solutions of the QPs using a recently devised iterative algorithm based on the principal directions (SVD) of their Hessians. Simulation examples have shown that performance degradation is small with respect to the optimal solution. In addition, the computational load is smaller since a feasible rather than optimal solution has to be obtained at each step.

A.18 Robust Stability of MPC

Researchers: Maria Seron, David Mayne (Imperial College, UK)

An important problem that arises in model predictive control in the presence of disturbances that are merely bounded, is that asymptotic stability of the origin cannot be established. The best that can be achieved is asymptotic stability of a set Z, often a disturbance invariant set, that has the origin in its interior. If Lyapunov theory is used to establish asymptotic stability of this set, it is useful to have a Lyapunov function that is zero (or non-positive) in this set (since the value of the function cannot be guaranteed to decrease in this set). Within this project we have adopted a novel approach to obtain a suitable Lyapunov function that has value zero in the set Z. The novelty is due to the fact that, in the proposed procedure, the 'initial state' in the optimal control problem solved online is a decision variable in addition to the usual control sequence. The incorporation of the initial state yields several important advantages: firstly, the value function is zero in Z, facilitating the proof of both attractivity and stability of Z; secondly, it permits the use of a terminal constraint set in the optimal control problem solved online that is not, as in the prior literature, equal to Z; thirdly it is possible, using this approach, to establish the strong result that the set Z is exponentially stable for the controlled system.

We have developed a novel solution to the problem of robust model predictive control of constrained, linear, discrete-time systems in the presence of bounded or exponentially decaying disturbances; exponentially decaying disturbances occur, for example, when observers are used to provide an estimate of the state of the plant and disturbance models. The solution is novel in that the optimal control problem that is solved online includes its initial state as a decision variable (in addition to the control sequence). This feature causes the value function to be zero in a disturbance invariant set that serves as the origin when bounded disturbances are present, and permits an unusually strong stability result, namely exponential stability of the disturbance invariant set for the controlled system with bounded disturbances. Exponential stability of the origin for the controlled system is established when the disturbance is exponentially decaying.

B. Mathematical Systems Theory

Program Leader: Iain Raeburn

Deputy Leader: Jose De Doná

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 Hilbert-space representations. Over the past decade, researchers have built up an elegant theory which describes the structure of the algebra in terms of the behaviour of cycles in the graph. Researchers in the Functional Analysis group at Newcastle have played a leading role in the study of graph algebras, but now many other groups all over the world are actively working in the area; there are several groups in each of Japan, Korea, the USA and Canada, for example.

The broad interest generated by this research recently led the American NSF to commit funding for a Regional Conference on the subject, which was held at the University of Iowa from 31 May to 4 June 2004. The central feature of the Conference was a series of 10 lectures by Iain Raeburn. He was invited to write a research monograph based on his lectures, to be published in the dedicated CBMS series by the American Mathematical Society. There were also five invited plenary lectures, two of which were given by investigators from CDSC: David Pask spoke on group actions on graph algebras, and Aidan Sims spoke on higher-rank graphs. This conference was a major focus for Iain in 2004: he spent much of March to May preparing the lectures, and since June has been working on the written version. The manuscript was submitted late in November.

Several members of the group continue to work on various topics associated to graph algebras, including several PhD students. In addition, Tyrone Crisp wrote a very fine honours thesis on corners in graph algebras.

B.2 Higher-rank Graphs

Researchers: Iain Raeburn, David Pask, John Quigg (Arizona, USA), Aidan Sims

Other support: National Science Foundation (USA)

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. (In this context, the word "building" refers to one of a family of higher-order combinatorial structures; these are central objects in the study of algebraic groups, which is itself a huge and very active area of contemporary mathematics with 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 of the graph.

Many of the properties of ordinary graph algebras have been extended to the algebras of higher-rank graphs, but in some respects the algebras of higher-rank graphs behave quite differently. Even for ordinary directed graphs, the ideal structure of graph algebras has only recently been completely understood (Hong-Szymanski, in press). In his thesis (submitted in November 2003), Sims tackled these differences head on, and has made a good start on understanding the ideal structure of the algebras of higher-rank graphs. In this project, he will continue to work on this problem, and efforts will be made to understand the topological invariants of the algebras of higher-rank graphs.

A major breakthrough in 2004 has been the discovery by David Pask, Iain Raeburn and Aidan Sims of a family of rank-2 graphs whose algebras are classifiable AT-algebras (that is, they can be written as direct limits of very nice algebras). This family includes examples whose algebras are those usually associated to irrational rotations on a circle, which are regarded by mathematicians as the most fundamental models of discrete dynamics with complex orbit structure. Sims gave a nice discussion of these algebras and their properties at the Centre retreat in October, and further progress was made during the visit of Rordam in November. Our investigations of this family of examples will be a top priority for 2005.

Another success in 2004 was the classification of coverings of higher-rank graphs by Pask, Quigg and Raeburn. One paper has already appeared (the benefits of electronic publication!) and a sequel has been submitted.

B.3 Groupoid Models

Researchers: Iain Raeburn, Cynthia Farthing (Iowa, USA), Paul Muhly (Iowa, USA), Trent Yeend (Student)

There are several ways in which one can approach the theory of graph algebras, and the analysis 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 based on groupoids, which provide an algebraic framework intermediary to the directed graph and the C*-algebra.

Groupoid models were used in the first analyses of the C*-algebras of infinite graphs in the mid-nineties, but these models were constructed in an ad hoc fashion. More recently, Paterson has developed a procedure for building groupoid models and has applied it to infinite graphs. The object of this project is to further develop Paterson's procedure and to apply to it to more general combinatorial structures, such as the higher-rank graphs of Kumjian-Pask and the continuous graphs of Deaconu and Katsura.

A groupoid model for higher-rank graphs was developed by Raeburn's student, Trent Yeend, in collaboration with Paul Muhly of the University of Iowa and Cynthia Farthing, who is a student of Muhly's and who spent nine months in 2003-2004 visiting the University of Newcastle. Their paper has been posted on the ArXiv. Yeend is currently writing his PhD thesis on the higher-rank analogue of continuous graphs; his main tool is a groupoid model, and many of his results are original even for ordinary (rank-one) topological graphs.

B.4 Construction of Wavelet Bases

Researchers: Iain Raeburn, Palle Jorgensen (Iowa, USA), Nadia Larsen (Oslo, Norway)

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 methods of constructing them.

During a visit by Iain Raeburn to Oslo in June, he and Nadia Larsen were consulted by Jorgensen about some phenomena arising in his work on wavelets. One aspect of Jorgensen's approach is the exploitation of operator relations exactly like those arising in graph algebras, and Larsen and Raeburn noticed that one could use the geometric information encoded in these relations to view a key construction as a computation of a specific direct limit associated to one of the operators. At the Centre retreat, Raeburn discussed how this simple idea underlies some of the basic constructions which relate filter banks in signal processing to wavelet bases.

B.5 Symbolic Dynamics and Operator Algebras

Researchers: David Pask, Teresa Bates (UNSW), Iain Raeburn, Wojciech Szymanski

A symbolic dynamical system consists of a collection of infinite sequences of symbols from an alphabet, together with a shift map which moves the sequences from right to left. A special class of symbolic dynamical system are the shifts of finite type, which are closely related to Markov chains. It is well known that a shift of finite type may be modelled by the infinite paths in a directed graph. The graph algebra of a directed graph is a C*-algebra which encodes the connectivity of the graph. In previous work it has been shown that many dynamical properties of a shift of finite type are reflected in the structure of the associated graph algebra.

In this current project we seek to expand this relationship between symbolic dynamical systems and C*-algebras. Every symbolic dynamical system over an alphabet may be represented by the infinite paths in a labelled graph, which is a directed graph whose edges are labelled by the given alphabet. We recover a shift of finite type, for example, by giving every edge a different label. The labelled graph algebra of a labelled graph is a C*-algebra which encodes the connectivity of the labels carried by the graph. If every edge has a different label, then the labelled graph algebra reduces to the graph algebra of the underlying directed graph.

We shall examine how the properties of the symbolic dynamical system manifest themselves in the associated labelled graph algebra. Preliminary results indicate that there are labelled graph algebras which cannot be realised as graph algebras (or even ultragraph algebras).

B.6 Coupled Oscillators

Researchers: Rick Middleton, Alejandro Rojas (Student), Jose De Doná

In this project, motivated by a particular biophysical example, namely intra-cellular calcium oscillations, we have studied a class of coupled oscillators in which there are 'weak' couplings between multiple 'strong' oscillators. Such oscillators admit approximation in terms of their phase behaviour which allows a simplified representation of the oscillators' state. In the simulations studied, this phase analysis can be seen to accurately approximate the true full order behaviour of the coupled oscillators, whilst significantly reducing the computations required to study their dynamics.

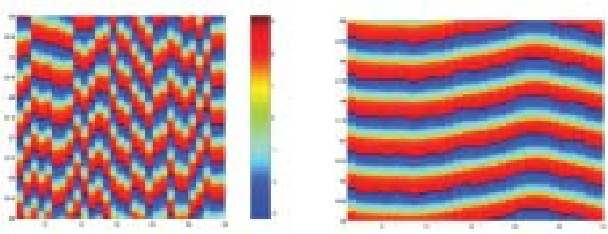


Figure 8: Simulations showing phase analysis of uncoupled and coupled oscillators

C. Bayesian Learning

Program Leader: Kerrie Mengersen

Deputy Leader: Richard Gerlach

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

Project Leader: Robert King

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

This project focuses on research into the behaviour, estimation and application of flexible distributions such as the g-and-k and g-and-h. This includes data fitting, modelling and estimation of extremes and quantile estimation.

The g-and-k and g-and-h distributions, like the earlier generalised lambda distribution (gld), are all defined by their inverse distribution function. For example, one representation of the gld is F-1(u) = 1+(u 3-(1-u) 4)/ 2 where 1 is a location parameter, 2 is a scale parameter and 3 and 4 jointly determine the shape. These distributions are of interest because of the wide variety of distributional shapes that they can take on.

The research in 2004 focused on developing a parametric regression method that allows great flexibility in the shape of the error distribution by modelling the errors with the generalised lambda distribution (gld). The new approach allows accurate estimates of 100(1-p)% prediction intervals in the face of severe departures from symmetry and with a wide variety of tailweights. Parameter estimation is via the starship method. Estimates of sampling variation are obtained via a parametric bootstrap method. An R package has been developed for implementation of the method.

A paper on this topic is currently under review: R King, R Gerlach and D Wraith, "Generalised starship regression using the generalised lambda distribution", Journal of Computational and Graphical Statistics.

C.2 Mixture Distributions

Project Leader: Kerrie Mengersen

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

This project focuses on research into Bayesian methods for mixture estimation, modelling and application.

The major activity in this project was the development of Bayesian nonparametric methods for the estimation of densities, goodness-of-fit assessment and the determination of set membership for transfer functions. This research was primarily undertaken by Research Associate Ross McVinish in collaboration with CIs Mengersen and Julio Braslavsky.

Nonparametric density estimation on [0,1] has been investigated using Bernstein polynomials and triangular distributions. In 2004, Ross McVinish established conditions for strong and weak consistency of the posterior distribution under two forms of triangular mixtures (fixed partitions and variable weights; fixed weights and variable partitions) that compare favourably with convergence of Bernstein polynomial representations. The behaviour of the Bayes factor in testing a uniform or parametric family against a nonparametric alternative using these triangular mixtures was also considered. Consistency of the Bayes factor can be obtained provided the nonparametric prior does not place too much probability near the parametric family. This work has led to a paper in preparation and comprises part of an invited presentation coauthored by Mengersen and McVinish and others at the International Statistical Institute (ISI) meeting in Sydney in April 2005.

A Bayesian approach was also developed for determining set membership for the transfer function describing a simple plant with an input-output system y=Gu+v where y is the output and G describes the plant acting on the input u which is observed subject to the noise v. A nominal model for G is used in the design of a controller for the plant. However, for the controller to be robust it is necessary to have an estimate of the uncertainty about the model – including unmodelled dynamics. Three approaches have been proposed: nonstationary embedding which models the unmodelled dynamics as a random walk, model error modelling which is based on prediction error methods, and set membership identification which aims to find a set of models that are compatible with the data and any assumptions on the system. The approach taken here was to consider the estimation of G from experimental input-output data using a Bayesian nonparametric method, in a similar spirit to set membership identification but different in the type of prior information that can be included and in the probabilistic nature of the sets formed. The approach proceeds by finding regions on Bode or Nyquist plots that possess high probability of containing the transfer function. The usefulness of this methodology in designing robust control mechanisms is under further investigation. This work has led to a paper accepted for presentation at an international workshop in 2005.

Also in 2004, PhD student Clair Alston progressed research under the supervision of Mengersen in Bayesian mixture models for analysing image data, with focus on CAT scans. The mixture models are used to describe interpretable components or clusters in the 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. The spatial model was demonstrated to be superior to the model that ignored spatial autocorrelation, although computation was substantially more demanding. The temporal model represented the parameters at time t+1 as perturbations of the same parameters at time t, with distributions imposed on the perturbations. This work has led to the publication of one paper and the submission of another.

In 2004, Mengersen and collaborators completed a large (50pp) invited review of Bayesian methodology for mixture modelling, which will appear in 2005.

Two other invited chapters focusing on Bayesian approaches in meta-analysis were written by PhD student Elizabeth Stojanovski, and will also appear in 2005.

A Bayesian mixture model for species divergence was developed in collaboration with visiting French student, Alexandre Adam and ex-PhD student (now CSIRO scientist) Peter Baker. This resulted in a published article, see page 32.

C.3 MCMC Algorithms

Project Leader: Kerrie Mengersen

Researchers: Richard Gerlach, Darfiana Nur, Ross McVinish, Ian Wood

This research involves the development and evaluation of computational tools for Bayesian Learning, including MCMC algorithms, reparametrisation, convergence and interpretation.

In 2004 this project has focused on three main areas. First, Gerlach and coauthors have adapted and compared Markov chain Monte Carlo algorithms in novel settings, including finance and neurology. Two papers on this work are under review: Rosso, Hyslop, WGerlach, Smith, Hunter, Rostas, "Quantitative EEG analysis of the maturational changes associated with childhood absence epilepsy", under review at Physica A.; and Gerlach, Park, Tuyl, "MCMC methods for comparing stochastic volatility and GARCH models", revised for International Journal of Forecasting.

Second, Mengersen was invited to provide an updated review of Markov chain Monte Carlo methods for the Encyclopedia of Biostatistics. This review, entitled "Markov chain Monte Carlo: An Update", will appear in early 2005.

Third, Dr Darfiana Nur concluded research on phase randomisation, obtaining simulation results that suggest that the third cumulative could be used as a convergence diagnostic for MCMC. Theoretical results confirming these conclusions were also derived. Two papers on this topic have been submitted for review: D Nur, K L Mengersen and R C Wolff (2002). "Phase Randomisation : A Convergence Diagnostic for MCMC". Accepted with revision by Australian and New Zealand Journal Statistics; and, D Nur, "Asymptotic distribution of Third Cumulants in Time Series", submitted to Computational Statistics and Data Analysis.

C.4 Time Series

Project Leader: Richard Gerlach

Project members: Darfiana Nur, Zahirul Hoque

This project focuses on research into the application and understanding of linear and nonlinear time series models. This includes forecasting dynamic models, and the application of time series models to MCMC convergence and hidden Markov models.

Dr Richard Gerlach has continued his research into Bayesian techniques for variable selection and model selection, using novel Markov chain Monte Carlo sampling schemes. Recent interest has focused on identifying thresholds in nonlinear time series. Such problems are particularly encountered in finance, for example to predict the direction of company earnings or stochastic volatility. The methods have also been applied to EEG models and are being extended to problems in other Programs in the Centre. As part of this work, Gerlach was coauthor of an invited paper to appear in 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.

Dr Darfiana Nur has continued her work on Bayesian analysis of Gaussian smooth threshold autoregressive (GSTAR) models, leading to a paper accepted for publication: N D Yatawara, M G Nair and D Nur, "Bayesian analysis of Gaussian smooth threshold autoregressive (GSTAR) models", Computational Statistics and Data Analysis.

C.5 Process Control

Project Leader: Kerrie Mengersen

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

This project focuses on research into Bayesian methods for statistical process control and improvement. This includes total quality management approaches, statistical tools for quality, sampling, methods for evaluating change and risk, and development of appropriate control charts.

Four main research activities for this project were undertaken in 2004.

First, Petra Graham, PhD student under the supervision of Program member Mengersen, completed and submitted her thesis, entitled "Statistical Methods for Assessing and Improving Quality in Hospitals". The approaches developed in this research are directly relevant to the Program research project and collaborative investigation with other Programs is under way to adapt them to control problems of mutual interest. A paper on reliability trees, which extend classification and regression trees to include information on the precision of nodal estimates, was submitted to Statistics in Medicine in 2004: P L Graham, P M Kuhnert, D A Cook, K Mengersen, "Improving the quality of patient care using reliability measures: a classification tree approach". A second paper by Graham, Mengersen and A P Morton, entitled "Control chart methods for hospitals" is in preparation for Statistical Methods in Medical Research. These approaches are being reviewed by PhD student Mr Paul Rippon in the context of industrial control.

The second activity was undertaken in collaboration with Dr Michele Haynes, University of Queensland and involved investigation of a Bayesian representation of the g-and-k distribution and development of corresponding MCMC techniques. This work resulted in an accepted paper in the international journal Computational Statistics, in 2004: M A Haynes and K L Mengersen, "Bayesian estimation of g-and-k distributions using MCMC". The use of this approach for process control is the focus of a paper in preparation by Haynes, Mengersen and Rippon.

The third activity was undertaken by PhD student Paul Rippon who, in collaboration with Mengersen, wrote an invited chapter to appear in Encyclopedia of Information Science in 2005 on Bayesian Learning: P Rippon, K Mengersen, "Bayesian Learning".

The fourth activity was the finalisation of research with visiting student Mohammad Salehi-Rad, who spent a year at the University of Newcastle as part of his PhD program in Iran. Mr Salehi-Rad developed new results for queuing models, which will be applicable to the Program activities in 2005. A paper on this work was published in 2004: M Salehi-Rad, K Mengersen, "Reservicing some customers in M/G/1 queues, under three disciplines".

D. Signal Processing

Program Leader: Minyue Fu

Deputy Leader: Graham Goodwin

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 equalisation, 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: Minyue Fu, Kaushik Mahata

A novel direct approach for modelling continuous-time stochastic processes is proposed in this project. First the observed data is passed through an input-to-state filter and the covariance of the output state is computed. The properties of the state covariance matrix are then exploited to estimate the positive real spectrum of the observed data at a set of prescribed points on the right half plane. Finally, the continuous-time parameters are obtained from the positive real spectrum estimates by solving a Nevanlinna-Pick interpolation problem. The estimated model is stable.

D.2 Multi-input Multi-output Wireless Systems

Researchers: Minyue Fu, Leif Hanlen

We consider the standard (point-wise) linear channel model for MIMO wireless systems in terms of a continuous operator channel. We show analytically that the point-wise representation over-estimates the (true) modal connection strengths and produces artificially distorted channel singular values. While the continuous model has a natural measure of its accuracy, such a measure does not exist for the point-wise case. Analytic results are compared with simulations for simple channel models and the convergence of the point-wise model toward the continuous model is shown.

D.3 Image Representation, Sampling and Reconstruction

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

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 the temporal dependence can be induced via motion. In this fashion the data consists of both spatial and temporal sampling. In this framework, we analysed the conditions for reconstruction for a number of typical motions.

In related work we have studied the problem of multi-dimensional signal reconstruction from nonuniform or generalised samples. Typical solutions in the literature for this problem, utilise 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. This result has obvious benefits in the context of the afore-mentioned problem. The results expand and generalise earlier work by other authors on the one dimensional case. Potential applications include 2D images and video signals.

D.4 On Ergodicity of Stochastic Signals for Multirate Systems

Researchers: Minyue Fu, Damien Marelli

Stochastic analysis of a multirate linear system typically requires the signals in the system to possess certain ergodic properties. Among them, ergodicity in the mean and ergodicity in the correlation are the most commonly used ones. We show that multirate operations and time-variant linear filtering can destroy these ergodic properties. Motivated by this fact, we introduce the notions of strong ergodicity in the mean and strong ergodicity in the correlation. We show that these properties are preserved under a number of operations, namely, downsampling, upsampling, addition and uniformly stable linear (time-variant) filtering. We also show that white random processes with uniformly bounded second moments are strongly ergodic in the mean and that mutually independent random processes with uniformly bounded fourth moments are jointly strongly ergodic in the correlation.

D.5 Closed Loop Identification

Researchers: Graham Goodwin, James Welsh, Juan Carlos Agüero (Student)

This project is concerned with various aspects of closed loop identification. Identification in closed loop is usually necessary, in industry for economical and/or safety reasons. Most plants (even stable ones) are subject to disturbances and long term drift that preclude open loop operations. A specific case occurs with storage systems (eg tanks). These are common in chemical plants and are difficult to operate in open loop. Closed loop operation for identification can also be helpful in the context of model based control design.

One issue that particularly excites us is the idea of "virtual" closed loop identification. The key idea here is that there need be no connection between the true controller and the one used for the purpose of indirect identification. We believe that this could have important implications especially if the real controller is nonlinear or ill-defined.

Nonlinear control is common in industry. Indeed, mechanism such as antiwindup and dead-zones are very commonly employed in practical controllers. Also, there is growing use of constrained model predictive control methods which are inherently nonlinear. This means that straightforward application of indirect identification is not possible since the traditional methods rely upon linearity of the control law to yield a linear closed loop transfer function. In our work, we have proposed the use of a virtual closed loop which employs a virtual linear controller rather than the actual controller. We then use a modified version of standard indirect identification procedures to take into account correlations between a derived reference signal and the noise.

In earlier work, described in the 2002 and 2003 annual reports, we studied the use of an exclusion zone in closed loop nonparametric identification. In recent work, we have used an alternative technique for regularisation to examine the asymptotic estimation properties and have shown that, not surprisingly, the results are qualitatively independent of the regularisation method.

D.6 Sub-Space Identification

Researchers: Graham Goodwin, Juan Carlos Agüero (Student)

Much has been written in the literature on the topic of sub-space identification. This appears to be one of the preferred methods for dealing with multivariable system identification problems. Indeed, these problems are known to be difficult. In part, this is due to the fact that, in general, the likelihood function is non-convex. Sub-space methods avoid the non-convexity issue by using a multi-step procedure which includes a singular value decomposition. Unfortunately, it is not easy to develop a recursive form of these sub-space algorithms due to the singular value decomposition step. We have borrowed ideas from the sub-space methodologies to develop a novel recursive algorithm. We have assumed that the Kronecker invariants for the system are known.

We have also developed a sub-space version of the virtual closed loop idea described in Project D.5.

D.7 Time Domain Identification of Wide Band Systems

Researchers: Graham Goodwin, Hugues Garnier (Nancy, France), James Welsh

A frequency domain approach to wide band identification was described in our 2003 report. In recent work we have extended these ideas to the time domain.

D.8 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 utilise 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 generalise well-known results for the linear case. We have also explored the implications of these results in nonlinear system identification.

Our ongoing goal in this project is to extend the results to Nonlinear Stochastic Systems. This raises more technical issues than are involved in the deterministic case addressed so far.

D.9 Super Resolution Spectral Analysis Using Noisy Data

Researcher: Kaushik Mahata

One of the major breakthroughs in the area of spatial and temporal spectrum estimation is the evolution of subspace based algorithms in the last decade. Such algorithms like ESPRIT and MUSIC are being employed in numerous applications, which include radar, GPS, sonar, geolocation, mobile communication, and nuclear magnetic resonance imaging. A common goal in all such applications is to resolve closely spaced signal sources from the received signal. Subspace algorithms are computationally efficient and exhibit good resolution property when the data signal to noise ratio is large.

Although the subspace algorithms are very popular, it is not clear why the performance of these algorithms degrades severely with decrease in the signal to noise ratio of the data. This is also of major interest – whether it is possible to improve the performance of the subspace algorithms at low signal to noise ratio.

In our recent investigation we have shown that the subspace algorithms can be seen as data dependent optimal notch filtering techniques. The estimation performance depends on the signal to noise ratio, length of the data record and the quality of the notch filters. When the signal to noise ratio is low we need notch filters of better quality to get the desired performance. This insight can be used to design subspace methods with improved resolution property.

E. Process Control and Optimisation

Program Leader: Rick Middleton

Deputy Leader: Julio Braslavsky

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 and human resources tailored to the needs of the Australian industry.

E.1 Integrated Mine Planning (BHP Billiton)

Project Leader: Karsten Weihe

Researchers: Greg Adams, Gary Froyland, Graham Goodwin, Merab Menabde, Kerrie Mengersen, Rick Middleton, Peter Stone, Robert Watts, Markus Weimer, Christoph Wich, Meimei Zhang

Integrated Mine Planning is a joint project between CDSC and BHP Billiton Melbourne Technology Centre. The project aims to develop methodologies and software that determines a mine and infrastructure configuration together with a strategic plan that maximises life-of-mine net present value (NPV) where the following factors need to be accounted for: metal price fluctuations; known mine grade uncertainties and ore-class variable processing rates; some opportunity storage: ie stockpiling with subsequent blending, or leaving high-grade ore unmined.

In 2004, Professor Karsten Weihe took over as the project leader and Dr Meimei Zhang was recruited as a research academic working on this project. Previous work in 2003 had formed the foundations for the modelling and mixed integer linear program (MILP) formulations of simpler versions of mine planning problems. During 2004, members of the Newcastle group visited BHP-Billiton Melbourne to discuss formulation and proposed solutions techniques for dealing with uncertainty in mine planning using concepts of mine planning 'flexibility'.

Following this, with the appointment of Dr Meimei Zhang, a key step in the project was to find an ultra-fast method to calculate a mining schedule with maximum NPV. Genetic Algorithms have been applied to this optimisation problem which needs to take into account processing and mining costs together with ore prices discounted over time. To this end, an algorithm combining Genetic Algorithms and Topological Sorting has been devised and implemented in C++. The software has been tested on seven problems from different types of pits to benchmark against the optimal solutions of mixed integer linear program (MILP). The test results show that the algorithm can produce near optimal solutions (within 2% gap to the optimal solutions).

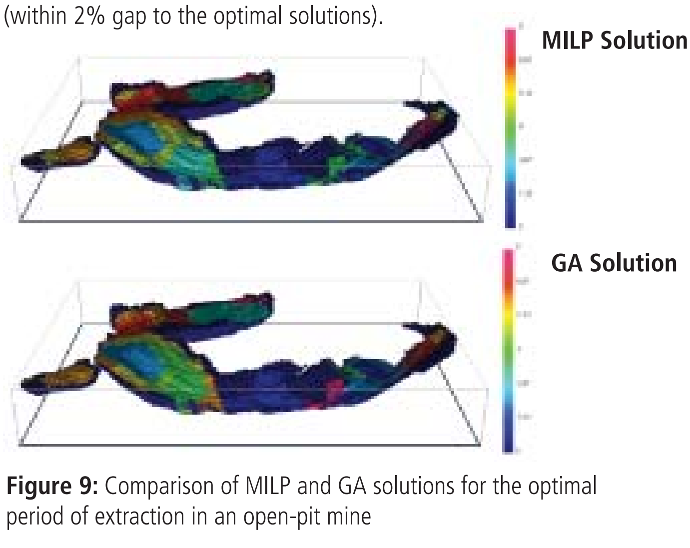


Figure 9: Comparison of MILP and GA solutions for the optimal period of extraction in an open-pit mine

However, as might be expected for this initial problem formulation, the consumed computational time on some large size problems is more expensive than that of MILP solutions.

Following recent consultations with the industrial partner, a new research focus has evolved which deals with the issue of joint cut-off grade, stochastic price variation and plant sizing optimisation. This approach aims to extend the theoretical basis of cut-off grade optimisation, initially pioneered in the 1970s by Ken Lane in his book "The Economic Definition of Ore", to suggest how cut-off grade should be optimised in a stochastic pricing environment.

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

Researchers: Julio Braslavsky, Boris Godoy (Student), Tom Honeyands, Katrina Lau, Rick Middleton, Steve Vandenberg

This project is funded by a partnership of the Centre with BHP-Billiton Innovation (Newcastle) and presently encompasses two main Industrial Case Studies described below.

Optimisation of The HBI Plant

BHP Billiton's HBI (hot briquetted iron) plant converts fine iron ore to direct reduced iron (DRI) which is compacted to form dense iron briquettes.

The chemical reactions take place in a series of four fluidised bed reactors. Ore is fed into the top reactor and flows down through the reactor train, whilst hot reducing gas enters the bottom reactor and flows in the opposite direction. The bottom reactor is connected to a pneumatic lift system (riser) which transports DRI up to the briquetting machines. The plant consists of four "trains", each containing four reactors and a riser, running in parallel.

An HBI Workshop was held on 27 February 2004, and was attended by a wide range of researchers from the Centre, as well as representatives from BHP Billiton. During the workshop several problems of potential interest to both BHP Billiton and the Centre were discussed. These included the following:

- Process Intensity (quantification of the amount of work being done by a process train)
- Process Capacity (quantification of the amount of work a train is capable of doing)
- Integration of the four trains (coordination of the four trains to meet overall plant specifications)
- Integration of an Internal Model Control scheme previously developed by the Centre into the operator guidance system

After the workshop, it was decided that we should concentrate on the problem of estimating the severity of accretions in the nozzle (the Riser Problem). The last reactor in each train is connected to the riser by a nozzle followed by a valve. When the valve is open, the pressure in the reactor forces hot, fine DRI through the nozzle then up the riser to the briquetting machines. Accretions may form in the nozzle because the particles flowing through it are at a high temperature and can be quite sticky. As accretions limit the flow through the train and hence affect process capacity, an estimate of the severity of accretion is useful.

Work on the riser problem has included the following:

- acquiring an understanding of the process,
- identifying some of the key difficulties of the problem,
- collecting and analysing signal data, and
- investigating the potential usage of various maximum, minimum, and `steady state' pressure measurements as indicators of the severity of accretion.

Preliminary results indicate that the maximum pressure drop across the nozzle (when the valve is open) is a useful indicator of nozzle blockage.

We note that the plant has been shut down since May 2004 and it is not known when the plant will resume production. Consequently, it has been decided that the project should be suspended at this stage. However, a detailed report has been written to summarise the current state of the project.

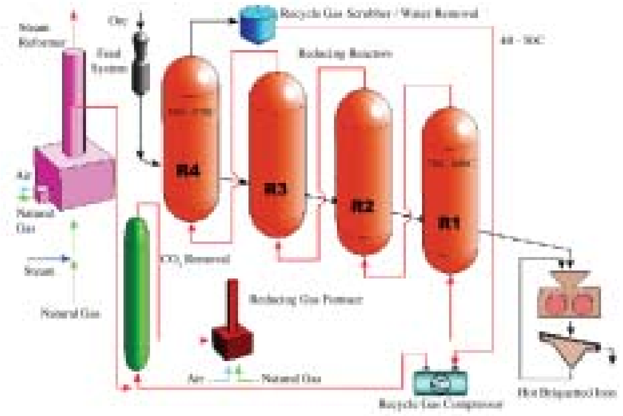


Figure 10: Schematic of the HBI process

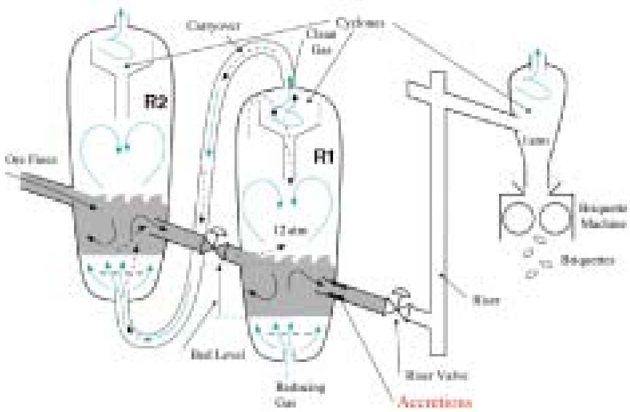


Figure 11: Diagram of the lower two reactors and the riser showing the location of the accretions

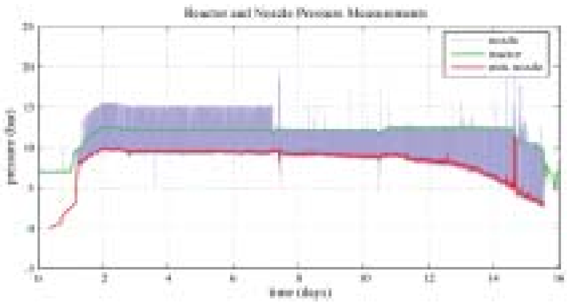


Figure 12: Graph showing the decrease in the minimum nozzle pressure (increase in the maximum pressure drop across the nozzle) as an accretion builds up in the nozzle

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 sulfur 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, and the raffinate is recycled to the top of the heap.

Boris Godoy has started his PhD studies this year working on the topic of control and optimisation of heap bioleaching. Initial work has produced a mathematical model of a simplified process, consisting of a single chemical reaction, but including all the main modelling aspects of a heap leaching process. Simulation results indicate that this model can be satisfactorily extended to include all chemical reactions arising in a typical real process.

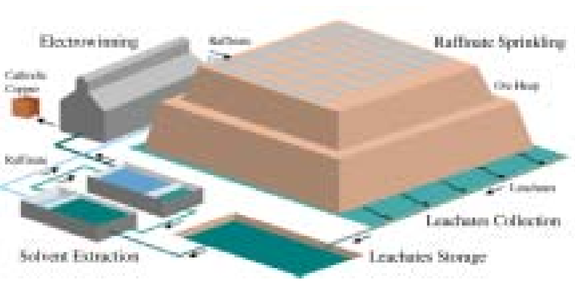


Figure 13: Heap leaching process

Figure 14: Collection of leachates from heap leaching (courtesy of CODELCO, Chile)

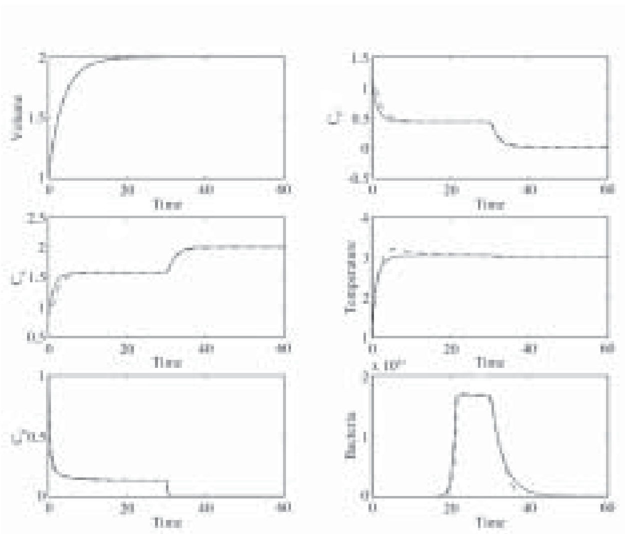


Figure 15: Simulation results for a single biochemical reaction process

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

Project Leader: Greg Adams

Researchers: Sam Crisafulli, Graham Goodwin, Adrian Medioli (Student), Rick Middleton, Maria Seron, Richard Thomas

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; integration of control tools with monitoring and diagnostic tools; and extensive human-machine interaction support.

Initially, development will concentrate on enhancing existing MPC software from Matrikon, and integrating knowledge and existing closed-loop identification software from CDSC. In 2004, work proceeded through a series of meetings amongst various groups from Matrikon and CDSC to determine features to be included into the new tools, a schedule for their implementation, and the division of labour amongst researchers and developers. One important task was to define the size, speed and other characteristics of problems that would form the market for the new tools.

Matrikon developers 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 the following.

The current MPC toolbox code and algorithm have been investigated. Some minor additions have been made, and some bugs have been fixed. Work has started on performing prior checks for infeasibility, related initially to setpoints and process variable constraints.

The closed-loop identification software has been investigated. Some problems have been found and fixed. Thus far, testing on three-input, three-output problems has been successful.

Benchmarking problems are being sought. So far, the Shell control problem and a binary distillation column have been investigated.

Basic work has been undertaken examining MPC control with state constraints for unstable systems. The example problem considered is stabilisation of a second order unstable system with limited control authority. In this case, there is a limited range of initial states that can be stabilised. Therefore, there are significant advantages to deliberately introducing state constraints to restrict the system to live in the stabilisable region. This approach substantially expands the region of attraction compared to what would otherwise have been achieved. In addition, we have noted that in the infeasible case, ie the case where the state constraint cannot be achieved with the control authority available, the traditional approach of constraint 'shedding' to permit a feasible solution is inappropriate, and other techniques of dealing with this problem need to be considered.

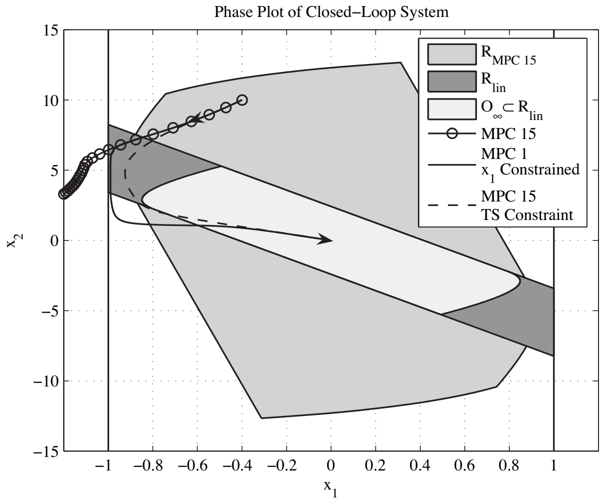


Figure 16: Phase Plot of Closed-Loop System

Future work on next-generation model-based control tools will investigate MPC strategies, optimisation algorithm improvements, constraint and feasibility issues, handling of process non-linearities, addition of diagnostic features for operators, improvements to the existing closed-loop identification strategy, finding more benchmarking problems, and gaining access to industrial processes for testing purposes.

E.4 Nutating Mill Control (Hicom International Pty Ltd.)

Researchers: Rick Middleton, Greg Adams, Graham Goodwin

This project is fully funded by Hicom International, who have developed a nutating grinding mill that offers very fast breakage rates per unit mill volume. A detailed functional specification and proposal for development of a control system for the Hicom mill was delivered in March 2004, encompassing control, optimisation and system identification aspects. In August, a contract for developing the control system was agreed to between CDSC and Hicom, and CDSC commenced development in October. The technical details of this project are confidential.

In June, a fourth-year project student, Damian McLean, completed his "Soft Sensor for a Grinding Mill" project. The goal of this work was to infer internal mill variables based on measurements of other mill conditions. The strategies developed here were to be included into the Hicom control system project.

F. Mechatronics

Program Leader: S O Reza Moheimani

Deputy Leader: Rick Middleton

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 Loop Shaping LQR Design for Vibration Control

Project Leader: Reza Moheimani

Researcher: Kathy Peterson (University of Michigan, USA)

Flexible structures are highly resonant systems and controllers designed for these systems are often lightly damped. Consequently, the closed-loop performance can be very sensitive to variations in the resonance frequencies of the structure. Indeed a small variation in a resonance frequency of the structure can bring about a significant change in open-loop gain and phase of the system. Therefore, when designing a controller for such systems, it is important to ensure that closed stability and performance are preserved with respect to variations in resonance frequencies of the system.

This research is inspired by the loop shaping methodology proposed by Sievers and von Flotow, in late 1980s, for vibration suppression of a thin beam. By augmenting the plant with bandpass filters, Sievers and von Flotow were able to isolate the response of specific frequencies and adjust the plant's response at these frequencies using LQR feedback. The advantage of this approach is that it provides a simple methodology for altering the frequency response of the plant at particular points of interest. In terms of flexible structures, such a technique can be used to reduce the response of the plant at its resonance frequencies.

The filters used by Sievers and von Flotow take the form F(s) = w02 /s2 + w02, which are highly resonant and thus create a highly resonant controller. Using this method to dampen the response of flexible structures is problematic as the locations of the resonance frequencies are often not known with absolute certainty. Thus small errors in the resonance frequency can lead to poor robustness. To improve robustness, we used Butterworth band-pass filters to enlarge the region penalised in the LQR cost function. This technique allows for a simple tuning procedure for the closed-loop performance.

It also results in controllers that are sufficiently robust with respect to uncertainties in the resonance frequencies of the structure.

Experiments were performed on a piezoelectric laminated thin beam to test performance of the proposed controller design technique. The main components of the experimental setup are; the dSpace DS1103 processor board, the spectrum analyzer, six piezoelectric patches, the laser vibrometer, and the beam. The six piezoelectric patches are arranged into three sets of collocated pairs along the length of the beam. The first collocated pair is located near the fixed end of the beam, the second collocated pair is located near the free end of the beam, and the third collocated pair is located near the centre of the beam as shown in Figure 17. The first and second collocated pairs act as actuators/sensors and the third pair is used to generate a disturbance in the beam. As only one piezoelectric patch is required to generate the disturbance, the redundant patch is shorted to remove its effect on the system.

Using the laser vibrometer to measure the tip displacement of the beam, the control goal is to minimise the response of the tip due to excitation of the disturbance patch. To do so, the control algorithm is encoded on the dSpace processing board which is capable of measuring the response of the piezoelectric sensors and driving the piezoelectric actuators. The spectrum analyzer is used to generate a sinusoidal chirp signal of varying frequency (from 5 to 250~Hz) to determine the frequency response of the system. In Figure 18, the spectrum analyser is shown connected to the laser vibrometer and disturbance patch.

A controller was designed and implemented on the multivariable system. Then a mass was attached to the tip of the beam, which resulted in a shift of about 10% in the resonance frequencies of the beam. The controller maintained closed-loop stability and performance of the system in a satisfactory manner, as illustrated in Figure 18.

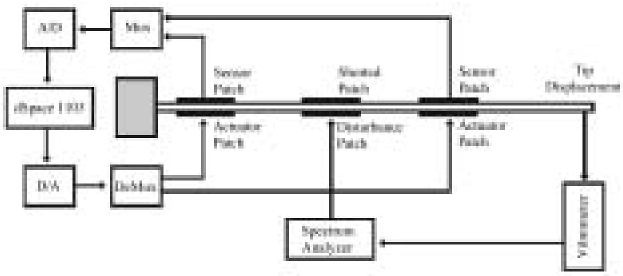


Figure 17: Beam experimental setup

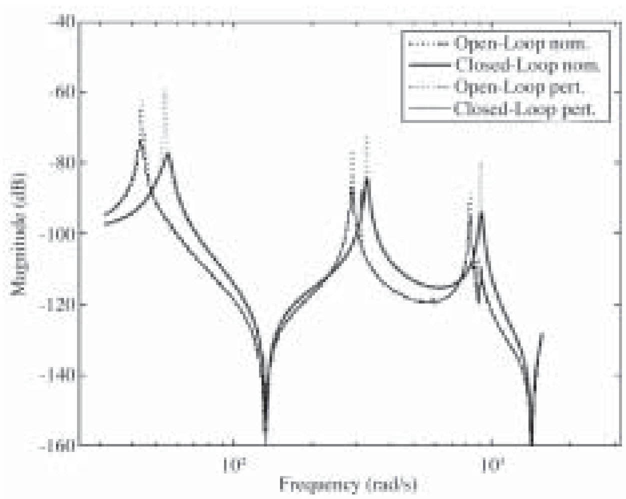


Figure 18: Experimental open-loop vs. closed-loop response from the disturbance to the tip displacement for both nominal and perturbed plants

F.2 Active Shunt Control of Electromagnetically Actuated Systems

Project Leader: Reza Moheimani

Researchers: Andrew Fleming, Sam Behrens

The purpose of this project is to suggest a framework for design of active sensor-less shunt controllers for electromagnetically actuated systems. Electromagnetic transducers are used as actuators, or sensors. In this research we illustrate that the functions of sensing and actuation can be integrated within the same electromagnetic transducer by applying a shunt to the terminals of the transducer. This is done by measuring the coil terminal voltage and controlling the resultant current, or vice versa. This approach removes the need for external sensors as the transducer functions in both capacities.

The problem can be reduced to that of a feedback control problem by augmenting the dynamics of the system with the shunted impedance/admittance and appropriately defining the plant and the feedback controller. The problem of designing a shunt is then reduced to that of designing a feedback controller for the augmented system. Consequently modern control design techniques such as H2 and H-Infinity can be employed to design a high-performance active shunt.

This idea was tested on a custom designed electromagnetic transducer. The system is essentially a mass-spring-damper system, as shown in Figure 19 in which a disturbance force is exerted on the mass applying a current to the first coil (see Figure 19a) and the second coil is shunted by an impedance to dampen vibration. A number of controllers were designed, and successfully implemented on this system. Figure 20 illustrates the feedback control problem associated with this framework, and Figure 21 shows performance of the shunted system for a H2 active shunt.

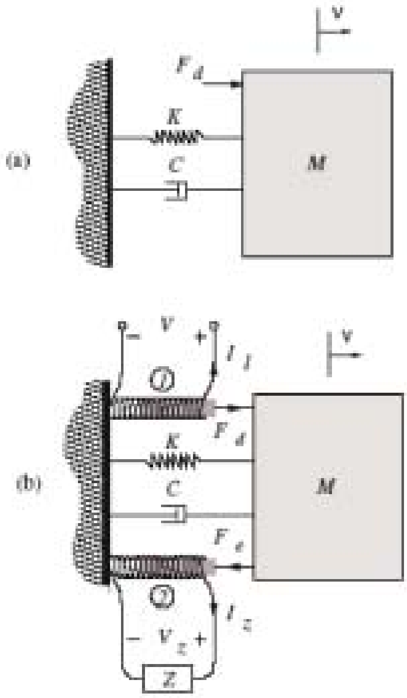


Figure 19: (a) Mass-spring-damper system; (b) Connected to two coils

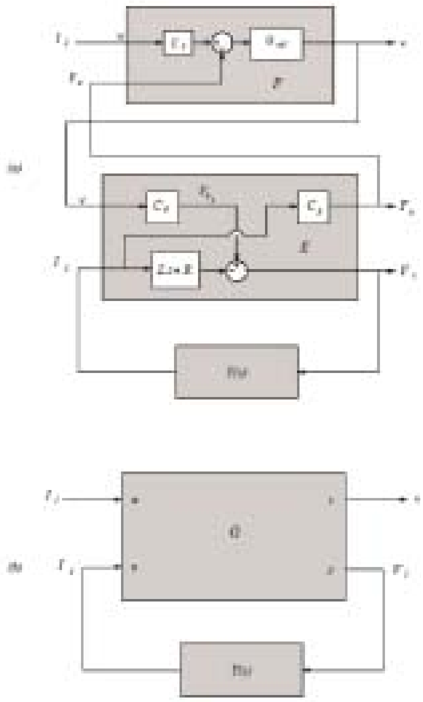


Figure 20: (a) The shunt admittance controlled electromechanical system; (b) Generalised plant/ controller form

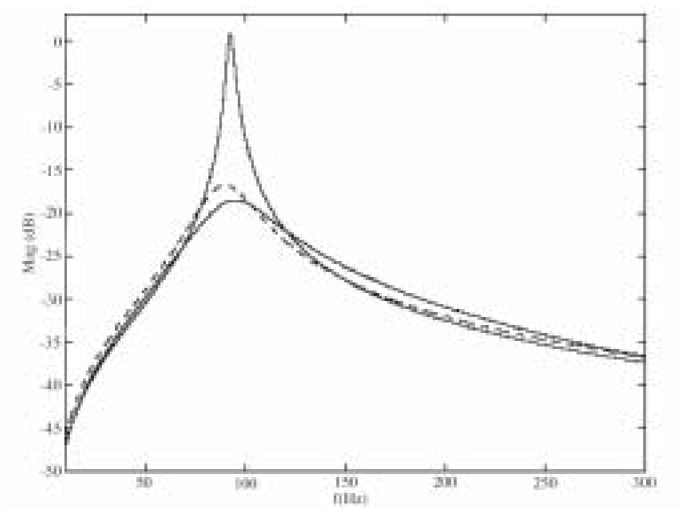


Figure 21: The experimental and simulated open-loop and shunted transfer functions with an H2 optimal impedance

F.3 Vibration Control Using Charge-driven Piezoelectric Actuators

Project Leader: Reza Moheimani

Researcher: Benjamin Vautier (Student)

Piezoelectric actuators, when driven by voltage amplifiers display significant hysteresis. Existence of hysteresis is known to adversely affect stability and performance of vibration control systems in which voltage driven piezoelectric transducers are used as actuators. It has been demonstrated that by controlling electrical charge, or current rather than the applied voltage, the hysteresis effect can be substantially reduced.

Even though this approach has been known since the late 1980s, it has not been widely used due to the perceived difficulty of driving highly capacitive loads such as piezoelectric actuators. The main problem is the existence of offset voltages in the charge or current source circuit, which will eventually charge up the capacitive load. This will then distort the control signal being applied to the piezoelectric load. However, due to our recent research, resulting in a new class of charge/current amplifiers, it is now possible to use electrical charge as the driving control signal for piezoelectric actuators in structural control applications.

When charge is used as the main driving mechanism for piezoelectric actuators, it is important to identify the structure of the underlying system, as this is slightly different from the voltage-driven case. In particular, the feedback structure of a flexible structure with a number of collocated charge-driven piezoelectric actuator/sensor pairs is illustrated in Figure 22. Here, is the transfer function matrix associated with the collocated system with voltage-driven piezoelectric actuators, and can be written as

$$G_{vv}(s) = \sum_{i=1}^{M} \frac{\psi_i \psi_i'}{s^2 + 2\zeta_i w_i s + w_i^2}$$

This observation enabled us to propose new classes of resonant controllers that are capable of guaranteeing closed-loop stability of the system, add significant damping to the structure and additionally roll off at higher frequencies. The latter is a particularly important property due to the high bandwidth nature of flexible structures. Two proposed controllers are described below.

$$K_v^{\alpha}(s) = \sum_{i=1}^{\hat{N}} \frac{\alpha_i \alpha_i' s^2}{s^2 + 2d_i \bar{w}_i s + \bar{w}_i^2}$$

and

$$K_v^{\beta} = \sum_{i=1}^{\hat{N}} \frac{\beta_i \beta_i' s\left(s + 2d_i \bar{w}_i\right)}{s^2 + 2d_i \bar{w}_i s + \bar{w}_i^2}$$

A controller was designed and tested on a multivariable resonant system shown in Figure 23. A multivariable model of the beam was obtained using frequency domain system identification and is shown in Figure 24. Performance of the controller can be observed from step response tests as plotted in Figure 24.

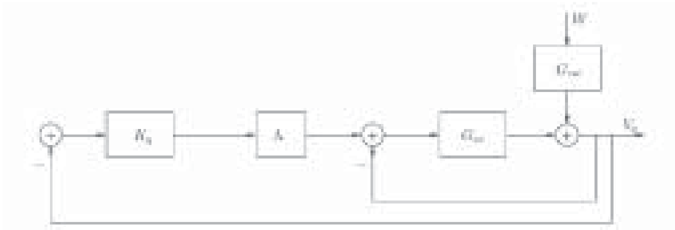


Figure 22: Feedback structure associated with charge-driven multivariable collocated piezoelectric actuator/sensor pairs

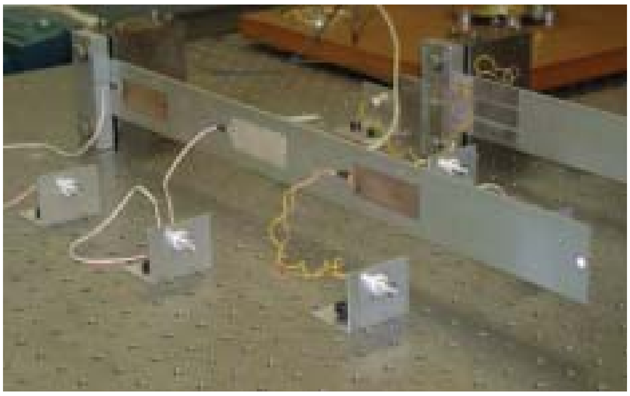


Figure 23: Picture of cantilevered beam

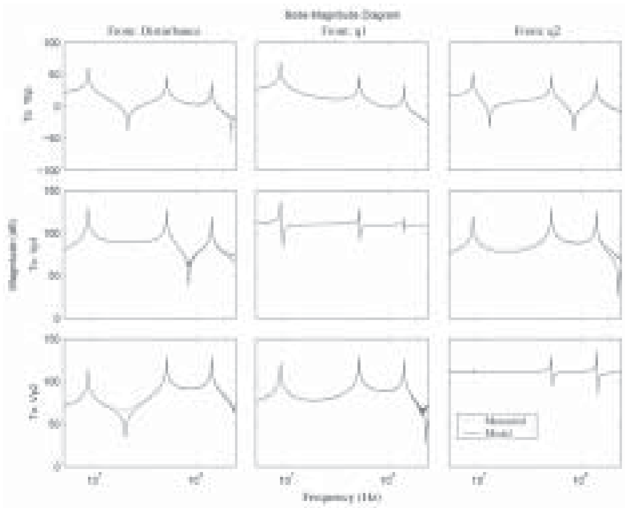


Figure 24: Identified model of the beam with measured and simulated data

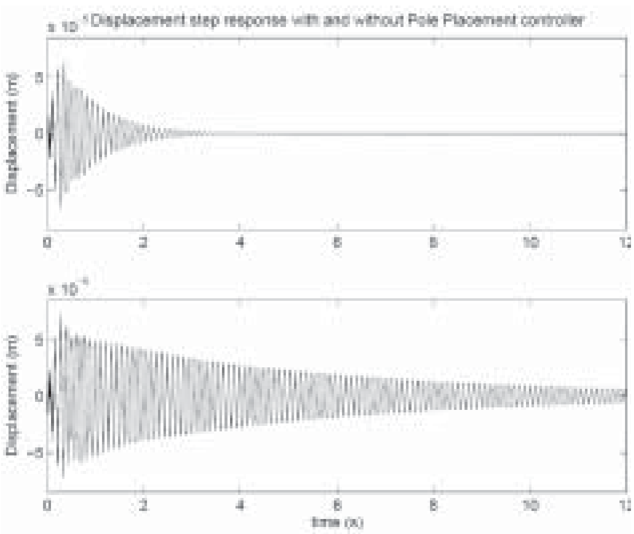


Figure 25: Step response of the open-loop and closed-loop systems

F.4 Electromagnetically Actuated Inertial Vibration Absorption

Project Leader: Reza Moheimani

Researcher: Andrew Fleming

Inertial drives and passive tuned-mass dampers utilise a suspended mass to reduce the vibration experienced by a host structure. The mechanical schematic and a photograph of an experimental system are shown in Figure 24 and Figure 27. Active vibration control systems typically employ a voice-coil type electromagnetic actuator in order to develop the required reaction forces. This project has introduced and proven the technique of sensor-less active shunt control applied to inertial vibration absorption. An electrical impedance is designed and connected to an electromagnetic coil with a view to minimising structural vibration. As shown in Figure 28, the electromechanical system can be cast as a standard optimal control problem, facilitating impedance design by synthesis techniques such as LQG and H-infinity. This technique requires no additional feedback sensors.

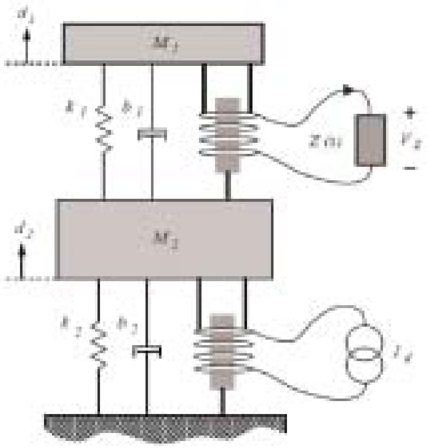


Figure 26: The vibration experienced by the system M2 is controlled by an auxiliary mass M1 and shunted electromagnetic transducer

Figure 27: Experimental inertial vibration controller

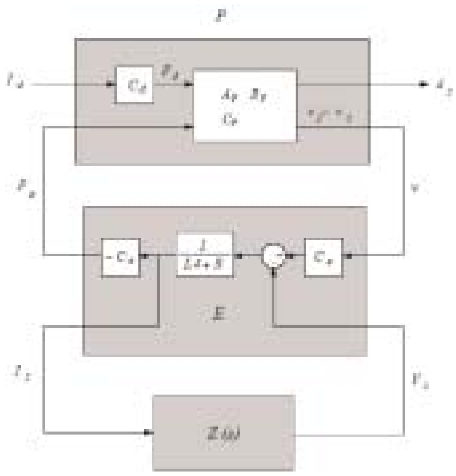


Figure 28: Experimental step response of an inertially controlled system (a) without control (b) passive control (c) H-infinity shunt controlled

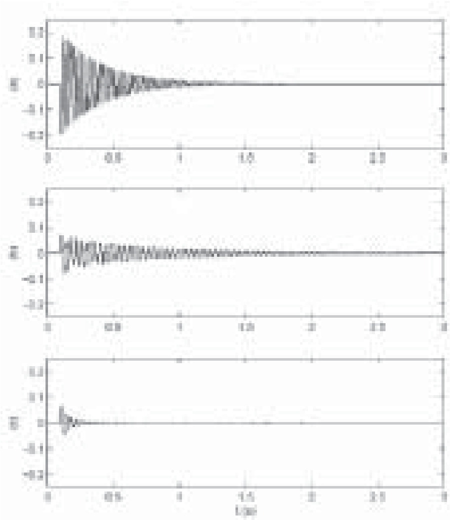


Figure 29: Experimental step response of an inertially controlled system (a) without control (b) passive control (c) H-infinity shunt controlled

F.5 Vibration Isolation and Scan Control of Piezoelectric Tube Nano-positioners

Project Leader: Reza Moheimani

Researcher: Andrew Fleming

Piezoelectric tube scanners are employed in high-resolution positioning applications such as scanning probe microscopy and nano-fabrication. Much research has proceeded with the aim of reducing hysteresis and vibration, the foremost problems associated with piezoelectric tube scanners. This project proposes two simple techniques for simultaneously reducing hysteresis and vibration. Experimental results demonstrate significant reduction in hysteresis due to the use of a charge amplifier. Standing problems associated with the electronics of such amplifiers are resolved to provide DC accurate performance with zero voltage drift. Piezoelectric shunt damping, a technique previously resident in the field of smart structures, has been applied to damp tube vibration. By attaching an LCR impedance to a single tube electrode, the first mechanical mode is reduced in magnitude by more than 20 dB. Experimental results illustrating the vibration reduction and ultra-low frequency stability of the electronics are shown in Figure 32 and Figure 33.

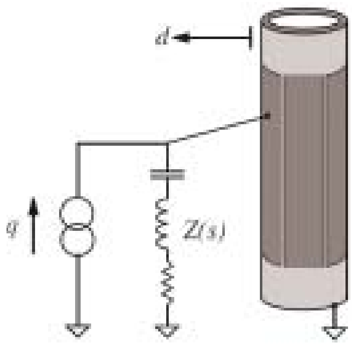


Figure 30: A shunted piezoelectric tube with charge drive applied to the same electrode

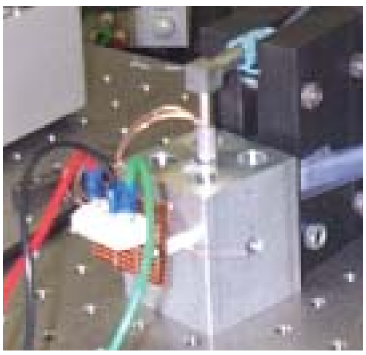


Figure 31: Experimental piezoelectric tube nanopositioner

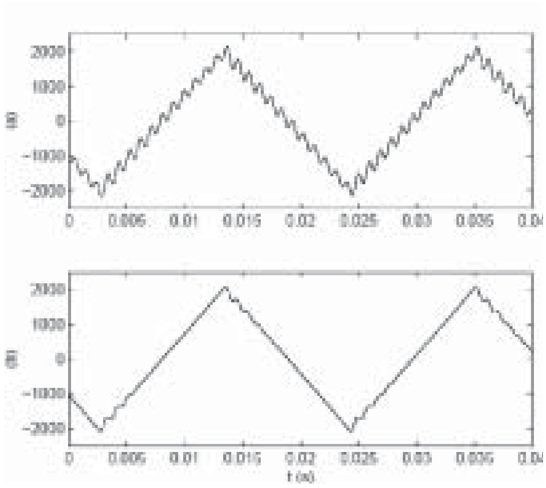


Figure 32: Measured displacement (in nm) of the nanopositioner shown in Figure 18 (a) before vibration control (b) with sensor-less scan control and charge drive

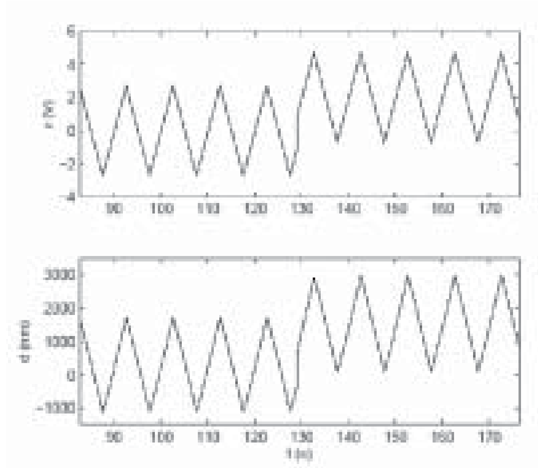


Figure 33: Reference signal (top) and measured displacement (in nm) of an ultra-low frequency scanning experiment. The DC tracking represents best reported performance achieved by a charge amplifier

F.6 Robot Soccer

Project Leader: Rick Middleton

Researchers: Stephan Chalup, Robert King, Michael Quinlan (Student), Craig Murch (Student), Tim Moore (Student), Yung Li Lee (Student)

During 2004, a new Sony Aibo model, the ERS7, was released and used for the robot soccer competition. This release prompted a number of revisions as several features of the robot changed from previous years. Specifically, the neck geometry was altered, a different camera was used, and the body and limb geometry was quite different. The NUbots team further developed the algorithms and software for the robot soccer. Some of the key innovations for 2004 were:

- The use of multiple look up tables for colour classification. This helps improve the reliability of colour recognition, particularly when objects are shadowed (for example, when looking down at the ball).
- Improved circle fitting algorithms for finding the ball. These included better heuristics for edge detection, and also some debugging which allowed greatly enhanced circle fitting to the ball.
- Multiple Model Kalman filters for localisation and world modelling. Late in 2003, and also in 2004, the code for the Kalman filter had been rearranged to support multiple models. These multiple models allow more advanced algorithms (for example, mixture models) to be run for localisation. This will be important in dealing with situations involving ambiguous data.
- Incorporation of "deadzones" into the extended Kalman Filter. It was observed during debugging that during extended periods of poor information to localisation, the estimated position of the robot could drift substantially. This 'drift' has been known in the different context of adaptive control, and can be attributed to the presence of small highly correlated error terms. One solution to this difficulty has been the use of a 'deadzone' which downplays, or even discards completely, measurement data when the new information, the innovation, is sufficiently small.
- There were also a number of enhancements to the locomotion algorithms, with new gaits and kicks being developed, and behaviour changes.

The team achieved third place in the world competition for the Sony 4-Legged League, again only losing a single game in the entire competition.

Activity Plan for 2005

Some of our main plans for 2005 are:

- Modern Industrial Control Short Course
- Apply for ARC LIEF funding to provide additional infrastructure for mechatronics control research
- Arrange the 2005 Centre Retreat
- Run a Workshop on "Constrained Control and Estimation", 7 – 11 February
- Advisory Board Meeting to be held on 8 April 2005
- Summer Systems and Control

Where are they now? Students who graduated in 2004

- **Simon Dodds**
  Laboratory of Analytical Chemistry, Chemometrics Research Department, Katholicke University of Nijmegen, The Netherlands.
- **Sam Behrens**
  Postdoctoral Research Fellow, CSIRO Division of Energy Technology, Newcastle, NSW.
- **Andrew Fleming**
  Research Academic, Centre for Complex Dynamic Systems and Control, the University of Newcastle.
- **Tristan Perez**
  Centre for Ships and Ocean Structures (CESOS) Marine Technology Centre NTNU, Trondheim, Norway.
- **Aidan Sims**
  School of Mathematics and Physical Sciences, the University of Newcastle.
- **Darren Woodhouse**
  Safe Earth, Energy Australia.
- **James Welsh**
  Lecturer, School of Electrical Engineering and Computer Science, the University of Newcastle.

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B.F. Hennessy, M.M. Seron and G.C. Goodwin, "MPC in Thickness Control of Single Stand Rolling Mill, Report No.2", November 2004.

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M. Weimer, C. Wich and K. Weihe, "Optimizing Flexibililty – A new approach to cope with uncertainty in the mining industry and beyond", July 2004.

B. Godoy and J.H. Braslavsky, "A First Study on Heap Bio-Leaching Modelling for Control", December 2004.

K. Lau, J.H. Braslavsky and R.H. Middleton, "HBI Riser – Report No. 1: System Description and Preliminary Data Analysis", December 2004.

HiCom International

G. Adams, "Hicom Special Control System: Functional Description and Proposal", March 2004.

G. Adams, "Hicom Special Control System: Interim Report for Stage 2", December 2004.

Matrikon

G.J. Adams, "Flash Furnace Smelter Control – Improvements to Feedback Controllers Using Step Testing", June 2004.

G.J. Adams, "Next Generation Model Predictive Control Tools – Analysis of Current PACTmpc Toolbox and Improvements to date", July 2004.

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G.C. Goodwin and G. Adams, "Next Generation Model Predictive Control Tools – An Overview of the These by Dr Leslie Bolton", December 2004.

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R.H. Middleton, "Report on Robustness Review of Total Channel ControlTM and FlumeGateTM", December 2004.

Other Publications

H. Tidefelt, "Applied Output Error Identification: SI-Engine Under Normal Operating Conditions", Masters Thesis, Submitted to Linkoping University, Sweden.

A. Rosén, "Air Fuel Ratio Control of an SI-Engine Under Normal Operating Conditions", Masters Thesis, Submitted to Linkoping University, Sweden.

Performance Indicators Report

(P.1) Research

Description	2003 Actual	2004 Actual	Details of 2004 Outcomes	2004 Target	03–07 Target
Refereed International Journal & Conference Publications	62	61	27 International Journal Publications see page 32 34 International Conference publications see page 34.	40	200
Patents	–	–			3
Major Presentations (Keynote etc.)	14	5	See Plenary Addresses page 32.	1	5
Science Citation counts for CDSC investigators	301	393	Search performed on ISI Web of Science, for all Centre Program 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	Details of 2003 Outcomes	2004 Target	03–07 Target
Recruit 25 Postgraduate Students	6	5	RHD commencements in 2004 (see page 4): Marcel Ratnam, Wang Meng; Adrian Medioli, Timothy Moore, Bryan Hennessy	5	25
Completed Research Higher Degrees	4	6	RHDs awarded in 2004 (see page 4): Simon Dodds; Andrew Fleming; Tristan Perez; Aidan Sims; James Welsh; Darren Woodhouse.	4	20
Supervise 1st Class Honours students	8	4	• Tyrone Crisp – "Corners in graph algebras", (Szymanski) • Adrian Monz – "Control of Stepper Motors" (Moheimani) • Damian McLean – "Soft Sensor for a Grinding Mill" (Adams) • Joshua Marshall – "Robocup Rescue Robot" (Middleton)	6	30
Professional Courses run	0	1	• Modern Industrial Control • Tutorial Workshop on Model Predictive Control – • Constrained Control and Estimation – • Bayes for Beginners and Bayesian QTL Analysis – See page 8	4	5
Senior undergraduate and postgraduate courses taught by Centre investigators in the area of complex systems	4	4	• ELEC4400 Automatic Control (De Doná) • ELEC4210 Electronics Design (Middleton) • STAT3120 Bayesian Statistics (Gerlach) • STAT3130 Financial Time Series (Gerlach)	4	20
Interactive Learning Laboratories developed	3	3	New modules completed in 2004: • Centre Line Thickness Control in Rolling Mills II (Periodic Disturbances and Observer Design) • Continuous Casting Machine I (Linear Control) • Continuous Casting Machine II (Nonlinear Issues (see page 14)	2	4

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

Description	2003 Actual	2004 Actual	Details of 2003 Outcomes	2004 Target	03–07 Target
International Research Visitors	19	19	See page 7.	10	50
Papers with international co-authors	14	7 9	See Journal Papers page 32. See Conference Papers page 34.	20	100
National and International Workshop organisation	4	5	Workshops: • Model Predictive Control Workshop • IFAC Symposium on Mechatronic Systems • Nonlinear Control Workshop • Constrained Control and Estimation • Bayesian Topics in the Tropics See page 8.	5	25
Visits to Overseas Labs	17	20	**Gerlach** Feng Chia University, Taiwan. **Goodwin** University of Strathclyde, Glasgow, UK; Universidad Tecnica Federico Santa Maria, Valparais, Chile. **Sims, A.** Department of Mathematics, University of Iowa, USA; Mathematics Institute, University of Rome (Tor Vergata), Italy. **Mengersen** INSEE, Paris, France; Santiago University, Chile. **Middleton** University of Alberta, Canada; University of Michigan, USA. **Moheimani** Data Storage Institute, Singapore; IBM Research Labs, Zurich, Switzerland. **Pask** Mathematics Insitute, University of Copenhagen, Denmark; Department of Mathematics, University of Nevada, USA; Department of Mathematics, University of Washington, USA; Department of Mathematics, University of Iowa, USA. **Raeburn** Department of Mathematics, University of Victoria, Canada; Department of Mathematics, University of Iowa, USA; Mathematics Insitute, University of Oslo, Norway. **Szymanski** Department of Applied Mathematics, Korea Maritime University, Busan, South Korea; Department of Mathematics, Polish Academy of Sciences, Poland.	10	50

(P.4) End-user Links:

Description	2003 Actual	2004 Actual	Details of 2003 Outcomes	2004 Target	03–07 Target
Postgraduate Students involved in industrial projects		7	**H. Haimovich** – General Motors Research **A. Medioli** – Matrikon **G. Godoy** – BHP-Billiton Innovation **T. Perez** – ADI **D. Quevedo** – Lake Technologies **A. Syaichu-Rohman** – Electricite de France **J. Welsh** – Matrikon	5	10
Visits by Centre Researchers to Industry	7		**Adams** HiCom International (Jan); Olympic Dam (May); BHP-Billiton Laboratories (Feb) **Goodwin** Industrial Automation Services 2 x Dec; 2 x Nov; June and July) **Middleton** Matrikon, Alberta Canada (May); Hydro Environmental (Nov); BHP-Billiton.	5	25

(P.5) Organisational Support:

Description	2003 Actual	2004 Actual	Details of 2004 Outcomes	2004 Target	03–07 Target
Annual cash contributions from collaborating organisations	$400K	$439,132	**Industry Support:** $155K **Universities:** $284,100	$450K	$2250K
In-kind contributions from collaborating Organisations			To be confirmed.	$1.5M	$7.5M

(P.6) Governance:

Description	2003 Actual	2004 Actual	Details of 2004 Outcomes	2003 Target	03–07 Target
Advisory Board	1	1	Advisory Board Meeting held 13 February 2004.		
2005 meeting to be held on 8 April.	–	–			

(P.7) National Benefit:

Description	2003 Actual	2004 Actual	Details of 2004Outcomes	2004 Target	03–07 Target
Student Placements in other organisations	5	7	**Sam Behrens** CSIRO Division of Energy Technology, Newcastle, NSW **Simon Dodds** Laboratory of Analytical Chemistry, Chemometrics Research Department, Katholicke University of Nijmegen, The Netherlands. **Andrew Fleming** CDSC, The University of Newcastle, NSW. **Tristan Perez** Centre for Ships and Ocean Structures, Marine Technology Centre, Trondheim, Norway. **Aidan Sims** CDSC, The University of Newcastle. **Darren Woodhouose** Safe Earth, Energy Australia **James Welsh** Lecturer, School of Electrical Engineering and Computer Science, The University of Newcastle.	2	10
Case Studies of Benefits			CDSC has agreed to co-fund, with Engineers Australia and other groups, a case study to be conducted by Emeritus Professor Mike Brisk		
Industry Technical Reports	9	23	See page 35.	5	25

Financial Statement

ARC Centre for Complex Dynamic Systems & Control
Statement of Income & Expenditure for the Year Ended 31st December 2004

Account name	Central Accounts (Combined)	Control System Design	Signal Pro-cessing	Process Control & Optimisation (Combined	Mechatronics	Mathematical systems theory	Baysian learning (UoN)	Baysian learning (QUT)	**TOTAL**
Account number	**P513–1438, 1430,1480, 1453, 1404**	**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									
2003 allocation b/f	154,264	10,052	133,700	185,372	99,038	60,425	61,078	100,000	803,929
Annual grant	79,203	401,000	242,000	367,728	246,000	129,000	124,000	120,000	1,708,931
Other income	8,600	0	0	146,432	0	0	0	0	155,032
University of Newcastle support	262,500	0	0	0	0	0	0	0	262,500
QUT Support	0	0	0	0	0	0	0	21,600	21,600
Total Income	**504,567**	**411,052**	**375,700**	**699,532**	**345,038**	**189,425**	**185,078**	**241,600**	**2,951,992**
SALARY EXPENDITURE									
Salaries (Academic)	175,835	179,942	118,293	282,838	84,091	44,264	0	74,876	960,139
Salaries (General)	108,155	35,478	0	0	4,195		0	4,034	151,862
Salaries on-costs	56,039	47,441	29,467	42,717	18,080	14,894	0	2,079	210,717
Scholarships	0	19,562	0	38,616	9,812	4,025	4,312	0	76,327
Total Salary and Related Costs	**340,029**	**282,423**	**147,760**	**364,171**	**116,178**	**63,183**	**4,312**	**80,989**	**1,318,056**
NON-SALARY EXPENDITURE									
Consumables	48,086	6,206	1,519	21,989	3,762	10,022	0	0	91,584
Services	6,943	41	0	216	162	0	0	0	7,362
Travel	30,527	36,471	6,637	36,124	47,246	0	0	3,298	160,303
Student Support	266	0	0	20,113	0	0	0	0	20,379
Repairs and Maintenance	2,808	515	0	0	0	0	0	0	3,323
Utilities	6,861	0	0	0	0	0	0	76	6,937
Equipment	6,411	0	0	0	0	0	0	366	6,747
Others	31,642	0	0	0	59	0		0	31,701
Total Non-Salary Expenditure	**133,544**	**43,233**	**8,156**	**78,442**	**51,229**	**10,022**	**0**	**3,710**	**328,336**
Total Expenditures	**473,573**	**325,656**	**155,916**	**442,613**	**167,407**	**73,205**	**4,312**	**84,699**	**1,727,381**
Balances as at 31/12/2004	**30,994**	**85,396**	**219,784**	**256,919**	**177,631**	**116,220**	**180,766**	**156,901**	**1,067,710**

Note: Estimated liabilities due to salary increases and post 2007 salary contracts approximately $M1.

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