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INCOME AND EXPENDITURE STATEMENT
OUR VISION

To be a world leader in analysis, design and optimisation of complex dynamic systems; pursuing outstanding fundamental and applied research.
Welcome to the 2007 Annual Report for the ARC Centre of Excellence for Complex Dynamic Systems and Control (CDSC).

We have had a productive year in terms of both basic research and contributions to industry. The details of the specific research achievements are presented in the sections related to the individual programmes.

Since our last Annual Report, there have been a number of developments which I briefly summarise below:

- Professor Richard Middleton (our former Director) took up a position with the Hamilton Institute in Ireland. We are pleased to report that Rick will continue to have substantial involvement with our centre via a part-time position which, inter-alia, will see him return to CDSC for a month each year.
- With the approval of the ARC, I was appointed Director to replace Rick in April 2007.
- A new position of Chief Operating Officer (COO) was established to assist with internal management issues. Dr Greg Adams accepted appointment to this position. Also, Dr Tristan Perez took up the newly established position of Industrial Liaison Officer.
- A new Industrial Affiliates Programme was introduced. Our long term goal is to have five new industrial groups join the centre. We are well advanced in meeting that goal with the following industries already signed up as Industrial Affiliates:
  - Industrial Automation Services
  - CSR
  - Connell Wagner
  - Halcyon International

Each of these affiliates brings new research collaborations to the Centre. Indeed, in the latter part of 2007 we began work on some of the projects and have already made good progress.

During 2007, we had a review from the ARC triggered by the departure of the Director. As a result of the feedback received during that review, we have made two changes to our report this year. These changes are aimed at giving a clearer picture of our research work.

The changes are:

i. We will, in this and future reports, include all publications written by members of the centre. (In the past, we only included publications arising from research 100% funded by the Centre.)

We believe that the inclusion of these other publications in our reports is important since it shows the totality of our research effort. Research funded from other sources is typically incubated within CDSC before reaching a size where it requires additional external funding.

Note that written descriptions of research funded outside CDSC are not included.

ii. We will include, for the first time, an ‘Outcomes’ section. This was suggested by the ARC Committee as a mechanism for giving greater exposure to the substantial industrial R&D work done in the centre.

On a personal note, I was honoured to be asked to join a Scientific Advisory Board for Lund University, Sweden and visited there in September. In total I made 6 overseas conference trips to Brussels, Cancun, Kos, New York, Quebec City, Valparaiso, Iguassu, Lund, St Louis and New Orleans. I also had the privilege of giving four Plenary/Keynote addresses in which I highlighted the research work of CDSC.

We believe that CDSC provides an exciting and vibrant research environment spanning basic research through to relevant industrial applications. The work would not be possible without the generous support of many organisations. In particular, we wish to gratefully acknowledge financial support from the Australian Research Council, NSW Department of Regional Development, The University of Newcastle, Queensland University of Technology, our industrial partners, and our newly joined Industrial Affiliates.

Finally, I would like to take this opportunity to express my thanks to the full CDSC team for their hard work and support during the past year.

Graham C. Goodwin
Director and Laureate Professor
STAFF

Director
Professor Richard H. Middleton
(unti April 2007)
Laureate Professor Graham C. Goodwin
(since April 2007).

Associate Directors
Professor Minyue Fu
Professor S.O. Reza Moheimani

Chief Operating Officer
Dr Gregory Adams

Program Leaders
Dr Julio Braslavsky
Industrial Control and Optimisation
Dr Maria Seron
Control System Design
Professor Reza Moheimani
Mechatronics
Professor Minyue Fu
Signal Processing
Professor Kerrie Mengersen
(QUT Node) – Bayesian Learning
Professor John Rayner
Bayesian Learning (UoN Node)
Associate Professor Brailey Sims
Mathematical Systems Theory

Other Chief Investigators
Dr Jose De Doná
Professor Iain Raeburn

Industry Liaison Officer
Dr Tristan Perez

Industry Partner Investigators
Dr Salvatore (Sam) Crisaulli
(Matrikon)
Dr Merab Menabde
(BHP-Billiton Innovation)
Dr James B. Lee
(BHP-Billiton Innovation)
Mr Peter Stone
(BHP-Billiton Innovation)
Mr Richard Thomas
(Matrikon)

Industrial Affiliates:
Industrial Automation
Services Pty Ltd
CSR
Connell Wagner
Halcyon International Pty Ltd

CDSC Funded Researchers
Dr Greg Adams
Dr David Allingham
Dr Sumeet Aphale
Dr Bharath Bhikkaji
Dr Andrew Fleming
Dr Mark Griffin (QUT)
Dr Peter Howley
Dr Robert King
Dr Katrina Lau
Dr Paula Lennon (QUT)
Dr Ross McVinish (QUT)
Dr Kaushik Mahata
Dr Pritha Mahata
Dr Damian Marelli
Mr Sean Moynihan (QUT)
Dr Claus Müller
Dr Darflana Nur
Dr Carlos Ocampo-Martinez
Dr David Pask
Dr Jaime Peters (QUT)
Dr Michael Quinlan
Dr Jacqui Ramagge
Dr Alejandro Rojas
Dr Aidan Sims
Dr Elizabeth Stojanovski
Dr W. Szymanski
Dr Frank Tuyl
Dr George Willis
Dr Ian Wood (QUT)
Dr Trent Yeend
Dr Yuenkuan Yong
Dr Mei Mei Zhang

Engineering Staff
Mr Frank Sobora

Support Staff
Mrs Dianne Piefke
Mrs Jayne Disney

STAFF MOVEMENTS

- Rick Middleton accepted a research
professorship from the Maynooth
Institute, National University of Ireland,
in May.
- Iain Raeburn, Jacqueline Ramagge, David
Pask and Aidan Sims all took up
positions at the University of Wollongong
in February.
- Tristan Perez accepted the position of
Industrial Liaison Officer and commenced
on 1 October.
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<th>Supervisor(s)</th>
<th>Degree</th>
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<td>Stephen Allen</td>
<td>&quot;Corners in graph algebra&quot;</td>
<td>D. Pask</td>
<td>PhD</td>
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<tr>
<td>Francisco Eduardo Castillo Santos</td>
<td>&quot;Aspect of metric fixed point theory&quot;</td>
<td>B. Sims</td>
<td>PhD</td>
</tr>
<tr>
<td>Ben Dean (Commenced 2007)</td>
<td>&quot;Modelling with the generalised Lambda distribution&quot;</td>
<td>P. Howley</td>
<td>MPhil</td>
</tr>
<tr>
<td>Milan Derpich</td>
<td>&quot;Sampling and quantisation in audio compression&quot;</td>
<td>G.C. Goodwin</td>
<td>PhD</td>
</tr>
<tr>
<td>Paul Fahey (Commenced 2007)</td>
<td>&quot;Analysis of performance data for universities and hospitals&quot;</td>
<td>R. King</td>
<td>PhD</td>
</tr>
<tr>
<td>Boris Godoy</td>
<td>&quot;Modelling and control of copper leaching processes&quot;</td>
<td>J.H. Braslavsky</td>
<td>MSc</td>
</tr>
<tr>
<td>Naomi Henderson</td>
<td>&quot;Improving robot vision using spatial and temporal correlations&quot;</td>
<td>S. Chalup/R.H. Middleton</td>
<td>PhD</td>
</tr>
<tr>
<td>Kenny Hong</td>
<td>&quot;Kernel methods for an adaptive online fact recognition system&quot;</td>
<td>S. Chalup/R.H. Middleton</td>
<td>MPhil</td>
</tr>
<tr>
<td>Wenbiao Hu (QUT)</td>
<td>&quot;Bayesian spatial-temporal CART&quot;</td>
<td>K. Mengersen</td>
<td>MAppSc</td>
</tr>
<tr>
<td>Sandra Johnson (QUT)</td>
<td>&quot;Bayesian networks&quot;</td>
<td>K. Mengersen</td>
<td>PhD</td>
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<tr>
<td>Jason Kuik (Commenced 2007)</td>
<td>&quot;Locomotion of a biped robot&quot;</td>
<td>J.S. Welsh</td>
<td>ME</td>
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<tr>
<td>Kate Lee (QUT)</td>
<td>&quot;MCMC algorithms&quot;</td>
<td>K. Mengersen</td>
<td>PhD</td>
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<tr>
<td>Christian Lovaas</td>
<td>&quot;Robust MPC&quot;</td>
<td>G.C. Goodwin</td>
<td>PhD</td>
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<tr>
<td>Iskandar Mahmood</td>
<td>&quot;System identification and robust control of spatially distributed systems&quot;</td>
<td>S.O.R. Moheimani</td>
<td>PhD</td>
</tr>
<tr>
<td>Trevor Marriott</td>
<td>&quot;Bivariate relationship modelling on bounded spaces with application to the estimation of forest foliage cover by Landsat satellite ETM-plus sensor&quot;</td>
<td>K. Mengersen</td>
<td>PhD</td>
</tr>
<tr>
<td>Adrian Medioli</td>
<td>&quot;Constraints, stability and feasibility issues in model predictive control&quot;</td>
<td>M.M. Seron</td>
<td>PhD</td>
</tr>
<tr>
<td>Steven Nicklin</td>
<td>&quot;Biped locomotion&quot;</td>
<td>R.H. Middleton</td>
<td>MPhil</td>
</tr>
<tr>
<td>Steven Mitchell</td>
<td>&quot;Physical interpretation of the broadband frequency response of power transformers&quot;</td>
<td>J.S. Welsh/R. H. Middleton</td>
<td>PhD</td>
</tr>
<tr>
<td>Chris Oldmeadow (QUT)</td>
<td>&quot;Bayesian latent variable models&quot;</td>
<td>K. Mengersen</td>
<td>PhD</td>
</tr>
<tr>
<td>Marcel Ratnam</td>
<td>&quot;Robust control of nano positioning systems&quot;</td>
<td>S.O.R. Moheimani</td>
<td>ME (Part time)</td>
</tr>
<tr>
<td>Paul Rippon</td>
<td>&quot;Statistical process control and goodness of fit&quot;</td>
<td>R. King</td>
<td>PhD</td>
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<tr>
<td>Cristian Rojas</td>
<td>&quot;Homonomous system identification&quot;</td>
<td>J.S. Welsh/R. Goodwin</td>
<td>PhD</td>
</tr>
<tr>
<td>Eduardo Silva</td>
<td>&quot;Performance limitations in networked control&quot;</td>
<td>G.C. Goodwin</td>
<td>PhD</td>
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<tr>
<td>Ian Searston</td>
<td>&quot;Analysis in geodesic metric spaces&quot;</td>
<td>R. King</td>
<td>PhD</td>
</tr>
<tr>
<td>Mark Smith</td>
<td>&quot;Ultramethods in metric fixed point theory&quot;</td>
<td>B. Sims</td>
<td>PhD</td>
</tr>
</tbody>
</table>
Ben Stewart-Koster (QUT)
Thesis Title: "Bayesian modelling in ecology"
Supervisor: K. Mengersen
Co-Supervisor: W. Venables
Degree: PhD

Fajar Suryawan (Commenced 2007)
Thesis Title: "Non linear model predictive control"
Supervisor: J.A. De Dona
Co-Supervisor: M.M. Seron
Degree: PhD

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

Wang Meng
Thesis Title: "Parsimonious information structures in real time signal processing"
Supervisor: G.C. Goodwin
Co-Supervisor: D. Quedevo
Degree: PhD

Natasha Weaver
Thesis Title: "Higher-rank graphs"
Supervisors: D. Pask and I. Raeburn
Degree: PhD

Lukasz Wiklendt
Thesis Title: "Learning and control in robotics"
Supervisor: S. Chalup
Co-Supervisor: M.H. Seron
Degree: PhD

Darren Wraith (QUT)
Thesis Title: "Bayesian mixture models for environmental health"
Supervisor: K. Mengersen
Co-Supervisor: S. Tong
Degree: PhD

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

THESES SUBMITTED IN 2007

Jose Maré
Thesis Title: "Dynamic programming solution to model predictive control"
Supervisor: J.A. De Doná
Co-Supervisor: G.C. Goodwin
Degree: PhD

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

GRADUATED 2007

Robert Denham
Thesis Title: "Bayesian models in ecology"
Supervisor: K. Mengersen
Degree: PhD

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

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

Michael Quinlan
Thesis Title: "Machine learning on AIBO robots"
Supervisor: S. Chalup
Co-Supervisor: R.H. Middleton
Degree: PhD

Alejandro Rojas
Thesis Title: "Feedback control over signal to noise ratio constrained communication channels"
Supervisor: R.H. Middleton
Co-Supervisor: J.H. Braslavsky
Degree: PhD

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

Dr Alejandro Rojas (left) with his supervisor, Professor Rick Middleton following the Graduation Ceremony.
The CDSC Advisory Board met in Newcastle on Friday 27 April 2007 to review progress, consider management issues and offer advice on strategic directions for the Centre.

CHAIRMAN
Professor Barney Glover
Deputy Vice Chancellor, Research, The University of Newcastle

CURRENT MEMBERS
Distinguished Professor
Brian D.O. Anderson
Research School of Information Sciences and Engineering, The Australian National University, Canberra, ACT

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

Dr S. Crisafulli
Matrikon, Warrabrook, NSW

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

Dr S. Galea
CSIRO, DSTO, Melbourne, Victoria

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, Melbourne, Victoria

Professor J. Carter
Pro. Vice-Chancellor, Faculty of Engineering and Built Environment, The University of Newcastle, Callaghan, NSW

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

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

Professor I.R. Petersen
School of Electrical Engineering Australian Defence Force Academy, UNSW, Canberra, ACT

Mr Gerard Noon
NSW Department of State & Regional Development, Sydney, NSW

Professor A. Sharma
Deputy Vice-Chancellor, Queensland University of Technology

Dr Brent Jenkins
Chief Executive Officer, TUNRA Limited, Callaghan, NSW

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

ACADEMIC

Dr Karina Barbosa
National Laboratory for Scientific Computing, Rio de Janeiro, Brazil.
August – May 2008

Dr Märtta Barenthin
KTH, Sweden.
November – December

Professor Paul F. Baum
Mathematics Department, Pennsylvania State University, Philadelphia, USA.
September – October

Dr Paulo Bertozzini
Department of Mathematics & Statistics, Thammasat University, Bangkok, Thailand.
September – October

Dr P. Chakraborty
Chennai, India
May

Dr Fedor De Ridder
Department of Electricity & Instrumentation (ELEC), Vrije Universiteit Brussels, Belgium.
January – March

Professor Santosh Devasia
Mechanical Engineering Department, University of Washington, Seattle, USA.
October – November

Dr Stephen Duncan
Department of Engineering Science, University of Oxford, United Kingdom.
October – November

Professor Arie Feuer
Technion – Israel Institute of Technology, Department of Electrical Engineering, Haifa, Israel.
July – October

Professor Jan Tommy Gravdahl
Department of Engineering Cybernetics, Norwegian University of Science & Technology, Trondheim, Norway.
July – July 2008

Dr Hernan Haimovich
Departamento de Electonica, Facultad de Cs. Exactas, Ingenieria y Agrimensura, Universidad Nacional de Rosario, Argentina.
March – May

Dr J.H. Hong
Department of Maths Maritime University BUSAN, Korea.
January – June

Dr Milutin Jovanovic
School of Computing, Engineering and Information Sciences, Northumbria University, Newcastle upon Tyne, United Kingdom.
December

Dr Kam Leang
Department of Mechanical Engineering, School of Engineering, Virginia Commonwealth University, Richmond, USA.
July – August

Professor Chris Lennard
Department of Mathematics, University of Pittsburgh, USA.
May
Professor Jean Lévine
Centre Automatique et Systémes, Ecole Nationale Supérieure des Mines de Paris, Fontainebleau, France. March – April

Dr Gang Li
Yangzhou University, P.R. China. September – December

Dr Jean-Michel Marin
Université Paris Dauphine, France. September

Associate Professor John Jairo Martinez-Molina
Département d'Automatique, GIPSA-lab, ENSIEG, Grenoble, France. July – August

Professor Emeritus David Q. Mayne
Control and Power Research Group, Department of Electrical & Electronic Engineering, Imperial College of Science Technology and Medicine, London, United Kingdom. April

Assistant Professor Sorin Olaru
SUPELEC, Automatic Control Department, Paris, France. May – June

Professor Dr Günter Schlichting
Mathematics Centre, Technical University of Munich, Germany. September – November

Professor Olivier Thas
Ghent University. February

Professor Paul Van den Hof
Delft Centre for Systems and Control, Delft University of Technology, Delft, The Netherlands. September – December

Dr Cathal Walsh (QUT)
Trinity College, Dublin, Ireland. January and December

Professor Vincent Wertz
CESAME, Université Catholique de Louvain Louvain-La Neuve, Belgium. August – January 2008

Professor Weizhou Su
Department of Electrical Engineering, South China University of Technology, Guangzhou, China. August

Professor Robert Wolpert (QUT)
Duke University, USA. November/December

STUDENT

Mr Raimondo Cau
Department of Mechanical Engineering, University of Technology, Eindhoven, The Netherlands. June – December

Mr Tai, Xin
National Laboratory of Industrial control Technology, Zhijiang University, Hangzhou, Peoples Republic of China. November – April 2009

Mr Flemming Scholer
Department of Electrical Engineering Aalborg University, Denmark. July – October

Mr Alain Yetendje Lemegni
Ecole Polytechnique, University of Marseille, France. February – June September – January 2008

Ms Audry Rossi; Ms May-Lan Nguyen
Mr Vincent Bozon
Ecole Polytechnique, University of Marseille, France. June – July

Ms Jennifer Tso
Auckland University, New Zealand.
A prime goal of CDSC is to combine outstanding fundamental and applied research to back Australia’s industrial competitiveness and capabilities. This section reports selected outcomes achieved in collaboration with our industrial partners during 2007.

For further information on how to establish an industrially linked research partnership with CDSC, contact the Industrial Liaison Officer, Dr. Tristan Perez, Tristan.Perez@newcastle.edu.au

**BHP-Billiton: Integrated Mine Planning**

“In 2007, BHP-Billiton benefitted from a several outcomes resulting from our on-going collaboration with CDSC within the project of integrated mine planning optimisation. These outcomes have contributed to a refinement of BHP Billiton’s current tools for mine planning. Among the results obtained, there is the formulation of the mine optimisation problem in a reactive way. The standard approach optimises the mine at the beginning of the mining operation, and the resulting schedule is followed through the life of the mine. In the reactive approach, the mine optimisation is re-evaluated as new information is available, and more emphasis is placed on the near future-non-uniform sampling. This approach allows flexibility in making decisions in the light of changed information during the life of the mine.

The mine optimisation must be performed in the presence of uncertainty in the ore content in the mine and in metal prices. In order to capture this, Monte Carlo simulations are performed to obtain potential scenarios. In order to have accurate results, a large number of simulations are required. CDSC has developed a novel technique called Hinged Stochastic Interpolation (HSI) as a means of scenario generation for decision making. This method generates a reduced set of representative scenarios, by which the distribution of uncertain quantities can be approximated. The application of HSI has demonstrated that the accuracy of estimates of the mining project valuation can be improved using a small number of price scenarios compared to using the same number of price scenarios from Monte Carlo simulations.

Other work undertaken in 2007 has addressed generating optimal practical mining phase designs from notionally optimal, but impractical, block extraction schedules. So far, this work has developed reliable methods for refining and reshaping the mining phases originally designed using BHP-Billiton’s proprietary optimisation tools.

The collaboration between the Business Optimisation Technology group at BHP-Billiton and CDSC has proven to be highly productive.

The development of core optimisation and modelling technologies by CDSC has made a material contribution to BHP-Billiton’s ability to build the best mine planning tools and then apply them to strategically plan and manage mining operations which are both sustainable and profitable. For 2008, we have identified some new key areas of research focus, including the development, identification and verification of higher order stochastic models of forward and spot commodity price, and we look forward to continuing collaboration with CDSC researchers”.

**Peter M. Stone**

Senior Principal Scientist

Business Optimisation Team

**BHP-Billiton: Sferics Project**

“Time domain electromagnetic (TEM) surveys are a principal technology used in the discovery of many types of mineral deposits, in particular those associated with conductive mineralisation such as nickel and silver/lead/zinc. To increase the depth at which TEM is able to detect mineralisation, and hence to allow additional resources to be discovered, the signal-to-noise performance of the TEM system must be improved. Sensor performance can be improved but system performance is ultimately limited by noise from natural sources such as sferics – originating from lightning discharges around the globe.

The Sferics project has developed techniques which allow sferics noise to be removed, to the extent that the noise performance of the system is again dependent on sensor noise, and sensor signal-to-noise improvements of between 10 and 40 times over current technologies will be achieved in the TEM system. Such an improvement doubles the depth accessible to TEM surveys, from 400m to 800m, and potentially doubles the chance of a discovery”.

**James B. Lee**

Senior Principal Scientist,

BHP-Billiton

Newcastle Technology Centre
Halcyon International Pty. Ltd., Western Australia: Improvement of ride control of marine vessels

"In 2007, Halcyon International was selected as the preferred bidder for the upgrade of the pitch and roll ride control systems of the current fleet of Bay Class Patrol Boats operated by the Australian Customs Service. The selection process was very competitive, and respondents included national and international competitors with strong corporate backing. The enhancement of Halcyon’s existing ride control system resulted from our collaboration with CDSC was instrumental in our successful bid.

The collaboration between Halcyon and CDSC resulted in the addition of three new functional features to the pre-existing control system. These new features were targeted to meet critical requirements identified by our client. An adaptive pitch and roll control allocation strategy was developed by CDSC to adjust the behaviour of the active trim flaps to suit changing vessel headings and wave environments. An active trim and heel controller was designed to operate in a low frequency range in conjunction with the higher frequency dynamic motion damping controllers. Finally, a smoothing control function was added to reduce structural wear as the system switched between different operational modes.

The innovative designs and technical advice provided by CDSC has assisted Halcyon in delivering the Australian Customs Service a superior ride control system upgrade for the Bay Class Patrol Boat fleet. Feedback from the Customs Service has been extremely positive and features praise for the flexibility and task focus of the development team. This project also won the 2007 Engineers Australia Western Australia award for excellence in engineering in the small business section.

Our collaboration with CDSC has been highly productive and commercially successful. The CDSC personnel were not only technically outstanding, but interacted with Halcyon in a professional and strongly outcome driven manner. Halcyon is now an affiliate partner of CDSC, and two new projects related to the areas of vessel motion control and wave energy conversion have been identified for further collaborations in 2008.

Paul Steinmann
Managing Director
Halcyon International Pty. Ltd.
28/589 Stirling Highway,
Cottesloe, 6011, Western Australia
www.halcyon.net.au

Tribotix Pty. Ltd.: New platform for multi-agent robotic systems

"In 2006, the organisers of the RoboCup 4-Legged League competition (for which the CDSC-sponsored NUbots team were runners-up in 2007 – see Selected Highlights) announced the call for tenders for a new robotics platform for their competition.

Tribotix Pty Ltd submitted a tender with the goal of pursuing the development of a new platform. This platform was completed with support from CDSC. The tender was eventually awarded to another consortium, but Tribotix is pursuing sales to other groups for research/educational purposes, and also to the wider community for entertainment/promotional purposes.

Mr Peter Turner
Managing Director
Tribotix Pty. Ltd.

Matrikon Pty. Ltd. (Asia-Pacific)

Matrikon are trialling the new model-based control tools, developed with major CDSC expertise, on the multivariable control of an Ethanol plant in southern USA.

Although the details are confidential, and more testing is needed, the preliminary results indicate significant improvement in operation and efficiency. Particular improvements in some unit processes are:

- Beer column: 5 to 10% reduction in energy (steam) usage.
- Mole Sieve: 0.5% improvement in throughput (500,000 litres per year).
- Slurry Sieve: Improved throughput for the same energy usage (tests ongoing).
- Dryer: 1.5% reduction in natural gas usage, and also better product quality.

Clearer results are expected to be reported in 2008. It is also intended, based on improvements such as those reported so far, to replicate the solution on many similar Ethanol plants. This will mean a significant multiplication of benefits to clients.
A number of courses and workshops were organised during the year. Details are:

**Flatness Based Control**
A course on Flatness Based Control Design (40 hours), was conducted in Newcastle, March-April 2007, and delivered by visiting Professor Jean Levine from Ecole des Mines de Paris, France.

**Spring Bayes**
The 4th Annual International “Spring Bayes” meeting was held on the Gold Coast in collaboration with the Australasian Society for Bayesian Analysis. The meeting was attended by about 40 people from three countries. Professors Jean-Michel Marin (USA) and Cathy Chen (Taiwan) and Dr Adrian (University of Queensland) were the three Keynote Speakers.

**Bayesian Statistics for Beginners**
This two day workshop was presented by Kerrie Mengersen in Sydney.

**Bayesian Regression Models**
Professor Jean-Michel Marin, visiting from France, delivered this two day workshop in Brisbane.

**London Mathematical Society Seminars**
George Willis presented a series of seminars funded by a London Mathematical Society Scheme 2 Grant.
- “Radical Banach Algebras”, Leeds University (May 16),
- “Totally Disconnected Groups and their Automorphisms”, Lancaster University (May 24), Newcastle upon Tyne (May 31) and Warwick University (June 6).

**Medical Imaging Retreat**
In November 2007 a retreat was organised between CDSC and the School of Psychology. The purpose of the retreat was to establish a relationship such with the prospect of future collaboration in the area of Medical Imaging between the two groups.

**Inversion-based Feedforward Control for Precision Tracking in Nonminimum-Phase Systems**
Professor Santosh Devasia, Department of Mechanical Engineering, University of Washington, Seattle, visited CDSC in October and November 2007. During this visit, Professor Devasia presented a three-day short course on Inversion-based Feedforward Control for Precision Tracking in Nonminimum-Phase Systems. This graduate-level course covered a number of advanced topics including: inversion-based control of linear SISO, MIMO and nonlinear nonminimum phase systems, robustness of preview-based control systems, optimal inversion, optimal transitions and practical applications of this theory. The short-course also included a number of hands-on Matlab sessions in which the attendees were given the opportunity to implement theoretical discussion in a laboratory environment.

**Industry Courses:**
In addition, the following short courses were delivered to industry:
- Queensland Transport: “Statistics in Transport”; one day course, Brisbane.
- Corrs Chambers Westgarth, “Environmental Risk”; one day course, Sydney.
- Orrcon: “Practical Quality Measurement”; three day course, Brisbane.

Dr Tristan Perez from CDSC delivered two courses (total of 35hours) in July at the Energy Division of ROBOTIKER-Tecnalia in the offices of Bilbao, Spain. The courses were on the topics of modelling and simulation of complex dynamic systems:

**Course 1:** Modelling and Simulation of Marine Structures in Waves.

**Course 2:** Modelling of Physical System Dynamics: Energy-based approach.

Dr Perez (centre) delivers two on-site courses on modelling and simulation of complex dynamic systems at the Energy Division of ROBOTIKER-Tecnalia, Bilbao, Spain.
SEMINARS 2007

Research students and staff from the Centre and the University of Newcastle as well as Australian and international visitors participate in the Centre’s seminar series. In addition to the seminars, the Centre holds a weekly informal seminar series to exchange information amongst researchers. Seminars presented in 2007 are listed as follows:

11 January
Professor Bengt Lennartson
Department of Signals and Systems, Chalmers University of Technology, Gothenberg, Sweden
*Numerical Sensitivity of LMIs and Efficient BDD-Algorithms for Formal Verification*

2 February
Dr Olivier Thas
Ghent University, Belgium
*Reweighted Smooth Tests of Goodness-of-Fit*

2 February
Mr Milan Derpich
CDSC, The University of Newcastle
*Sequential Quantisation of Frame Expansions*

2 February
Mr Trevor Moffiet
The University of Newcastle
*Bivariate Relationship Modelling on Bounded Spaces with Application to the Estimation of Forest Foliage Cover by Landsat Remote Sensing*

2 March
Dr George Willis
University of Newcastle
*Variations on the Theme of Eigenvalues*

3 April
Professor Murray Aitken
Department of Psychology, University of Melbourne
*A Model-free Bayesian Analysis of Clustered and Stratified Survey Data*

28 March
Mr Trevor Moffiet
The University of Newcastle
*Bivariate Relationship Modelling on Bounded Spaces with Application to the Estimation of Forest Foliage Cover by Landsat Remote Sensing*

28 March
Mr Cristian Rojas
CDSC, The University of Newcastle
*Issues in Robust System Identification*

2 May
Dr Andrey V. Savkin
School of Electrical Engineering and Telecommunications, The University of New South Wales, Sydney, Australia
*Estimation and Control Over Communication Networks*

5 March
Professor Andrey V. Savkin
School of Electrical Engineering and Telecommunications, The University of New South Wales, Sydney, Australia
*Estimation and Control Over Communication Networks*

2 May
Mr Frank Tuyl
The University of Newcastle
*Estimation of the Binomial Parameter: In Defence of Bayes (1763)*

7 March
Mr Frank Tuyl
The University of Newcastle
*Estimation of the Binomial Parameter: In Defence of Bayes (1763)*

22 March
Mr Paul Rippon
The University of Newcastle
*Competing with the Welch Test in the Behrens-Fisher Problem*

2 May
Mr Paul Rippon
The University of Newcastle
*Competing with the Welch Test in the Behrens-Fisher Problem*

15 June
Ngoc Tran
The University of Newcastle
*Vietnam Household Living Standard Survey*
20 June
Professor Chris Lennard
Mathematics Department, University of Pittsburgh, USA
“A Characterisation of Frames in Terms of Riesz Bases”

22 June
Dr Ian Benn
The University of Newcastle
“A Short and Informal Introduction to Statistical Mechanics”

27 July
Professor John Rayner
The University of Newcastle
“Smooth 2”

8 August
Dr John Jairo Martinez Molina
Grenoble Institute of Technology (INP-Grenoble), France
“Modelling and Robust Control of High-Density Optimal Disc Drives”

13 August
Dr David Allingham
The University of Newcastle
“Analysis of DNA Sequence Segmentation using Approximate Bayesian Computation”

13 August
Dr Elizabeth Stojanovski
The University of Newcastle
“Bayesian Meta-Analysis of the Relationship Between Life Events and Breast Cancer”

13 August
Dr Darfiana Nur
The University of Newcastle
“Sensitivity of Priors in Bayesian Analysis of DNA Sequence Segmentation”

21 September
Dr Mark Griffin
School of Mathematical Sciences, Queensland University of Technology.
“Medical Image Analysis and Spatial Statistics”

10 October
Professor Vincent Wertz
CESAME, Université Catholique de Louvain, Louvain-La Neuve, Belgium
“Multivariable Control of Cement Mills”

23 October
Professor Jonathan M. Borwein
FRSC, Computer Science Faculty, Dalhousie University, Halifax, Canada
“Interdisciplinarity: What Works, What Doesn’t?”

13 November
Professor Paul M.J. Van den Hof
Delft Centre for Systems and Control, Delft University, The Netherlands
“An Alternative Paradigm for Probabilistic Model Uncertainty Bounding in Prediction Error Identification”

15 November
Reader Stephen Duncan
Department of Engineering Science, University of Oxford, United Kingdom
“The Design of a Beam Stabilisation System for a Synchrotron”

22 November
Dr Carlos Ocampo-Martinez
CDSC, The University of Newcastle
“Model Predictive Control of Complex Systems: Application to Sewer Networks”

22 November
Professor Jan Maciejowski
Cambridge University

28 November
Ms Märtha Barenthin
School of Electrical Engineering, KTH - Royal Institute of Technology, Sweden
“The Cost of Complexity in Identification of FIR Systems”

29 November
Professor Jan Tommy Gravdahl
Department of Engineering Cybernetics, Norwegian University of Science & Technology, Trondheim, Norway
“Recent Results Within Modelling and Active Control of Centrifugal Compressors”

30 November
Mr Ian R. Griffiths
School of Electrical Engineering & Computer Science, The University of Newcastle
“Markov Chain Monte Carlo Methods for MIMO Detection”
SELECTED HIGHLIGHTS 2007

- Rick Middleton was appointed Associate Editor At Large (AEAL) of the IEEE Transactions on Automatic Control (Nov 2007).
- Reza Moheimani has been elected as a Fellow of the Institute of Physics (United Kingdom).
- The CDSC team was placed 2nd in the RoboCup World Championship 4 Legged League in Atlanta, USA.
- Rick Middleton was invited to participate in the NATO Lecture Series Presentations. (3hr lectures, funded by NATO Research and Technology Organisation; delivered in Rostock and in Florence).
- Andrew Fleming and Reza Moheimani won the 2007 IEEE Transactions on Control Systems Technology Outstanding Paper Award for their paper entitled “Sensorless vibration suppression and scan compensation for piezoelectric tube nanopositioners”.
- Steve Mitchell won Best student paper award at AUPEC 2007.
- Frank Tuyl won the Best Student Poster Award at the International Conference on Objective Bayesian Methods (OBayes), Rome, June 2007.
- Kerrie Mengersen was funded by the Australian Academy of Science for a month (June) at Universite Paris Dauphine collaborating with colleagues Professors Robert, Rousseau and Marin.
- Kerrie Mengersen continued as Managing Editor of the Australian and New Zealand Journal of Statistics, July 2005, an elected Fellow of the Institute for Mathematical Statistics, a member of the Advisory Board of the Bayesian Analysis Journal and a member of the Wesley Hospital (Uniting Healthcare) Research Committee.
- Kate Lee, CDSC PhD student, won the Wiley ‘best poster’ prize at Spring Bayes 2007.
- Carla Chen, CDSC PhD student, won the best poster prize at the International Biometrics Society Conference in December, 2007.
- CDSC held its annual retreat in October. The day was attended by all Centre academic staff, general staff, postgraduate students, visitors, as well as representatives from industry.
- Graham Goodwin joined a Scientific Advisory Board for Lund University.
- Graham Goodwin presented a Plenary Address: “Robust System Identification” at the 8th International IFAC Symposium on Dynamics and Control of Process Systems, in Cancun, Mexico.
- Graham Goodwin presented a Plenary Address: “Optimisation: A key tool for advanced design in scheduling, estimation and control” at the 12th IFAC Symposium on Automation in Mining, Mineral and Metal Processing, Quebec, Canada.
- Graham Goodwin gave a series of three Keynote Lectures at the Bennelux Meeting on Systems and Control.
- Graham Goodwin presented the Distinguished Zaborsky Lectures at Washington University.
- The 4th annual international meeting, “Spring Bayes” was held on the Gold Coast in collaboration with the Australasian Society for Bayesian Analysis. The meeting was attended by about 40 people from three countries. Professors Jean-Michel Marin (USA) and Cathy Chen (Taiwan) and Dr Adrian (University of Queensland) were the three Keynote speakers.
- Kerrie Mengersen made a Keynote presentation at ISOSS – Islamic Countries Statistical Societies Conference, Kuala Lumpur, 12–14 December: “Bayesian Learning”.

RESEARCH PROGRAMS
A. INDUSTRIAL CONTROL AND OPTIMISATION

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 five 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 arises 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.

A.1 NEXT-GENERATION MODEL-BASED CONTROL TOOLS (MATRIKON)

Project Leader: G.J. Adams

Researchers: D. Francois (Louvain-La Neuve, Belgium), G.C. Goodwin, A. Medioli (Student), R.H. Middleton, M.M. Seron, R. Thomas (Matrikon), J.S. Welsh, V. Wertz (Louvain-La Neuve, Belgium)

This project is funded by a partnership of the Centre with Matrikon Pty. Ltd. (Asia-Pacific)

A.1.1 Next Generation Model Based Control Tools for Matrikon

The aim of this industry project is to deliver to Matrikon process control tools that allow
- appropriate handling of complex, nonlinear and heterogeneous processes;
- robust and easy-to-use system identification;
- economic optimisation of process variables;
- integration of control tools with monitoring and diagnostic tools; and
- extensive human-machine interaction support.

Research in 2007 focussed on enhancing existing MPC software from Matrikon, and integrating knowledge and existing closed-loop identification software from CDSC. Matrikon developers and CDSC researchers have so far implemented a number of high-priority features to enhance marketability and usefulness of PACTmpc. CDSC contributions include:
- QP algorithm improvements.
- Soft constraint advice and testing.
- Handling of non-linear processes.
- Decoupling strategies that are intrinsic to the internal QP objective function (see the description in Project A.1.3).

Matrikon have applied the closed-loop identification tools (PACTmpcid) to an ethanol plant in Queensland, and further enhancements are being considered to the toolset.

Matrikon engineers in Texas have also applied PACTmpc to an ethanol plant. Early impressions are that the application of PACTmpc has improved the plant control significantly, with upwards of $1M dollars in cost reductions annually. The solution is intended to be replicated across up to 50 similar ethanol plants in the U.S.

Future work on next-generation model-based control tools will investigate:
- Further development of strategies for control of non-linear processes.
- Extending and integrating the economic optimisation features.
- Decoupling research and implementation.
A.1.2 Alarm Data Classification
Researchers: G.J. Adams, D. Francoise (Louvain-La Neuve, Belgium) and V. Wertz (Louvain-La Neuve, Belgium)

A second project involves alarm data classification and fault prediction. Matrikon hope to bring together their alarm data software (ProcessGuard) and failure code software (ProcessMÖRe) to allow the automatic generation of failure codes from alarm sets. A CDSC visitor from Belgium, (Professor Vincent Wertz) is working with his Belgian colleague (Damian Francois) to analyse some alarm data sets for useful identifiers, and has generated some predictions of failure codes. An example of this is shown in Figure 1, which shows the proportion of failure codes (on the left axis) that are classified as the correct failure codes (on the top axis).

A.1.3 Reduced Coupling in Model Predictive Control
Researchers: R.H. Middleton and G. Adams

Model Predictive Control (MPC) is a popular paradigm for modern control of multivariable processes. It allows process models to be used together with on-line optimisation to handle complex processes, and a variety of control performance and constraints to be incorporated. In many cases, however, there are no simple means to penalise cross-coupling in the closed loop response of the MPC system. In general, with both diagonal actuator and output cost function, MPC gives a closed loop response that is cross coupled, even in cases where a simple static decoupler would solve this problem. In this line of research we examine simple intuitive techniques for reducing this coupling that can be easily incorporated within the MPC framework. Some results for a 2x2 system are shown in Figure 2.

Figure 1: Proportion of actual failure codes (LHS axis) correctly classified (red is high, blue is low).

Figure 2: Reduced coupling in setpoint change responses for a non-minimum phase 2x2 system with input constraints.
A.2 EVAPORATOR CONTROL (CSR)

Project Leader: G.J. Adams

Researchers: G.C. Goodwin, J.T. Gravdahl (Norway) and AJ. Rojas

This project is part of CSR’s Affiliates Program involvement. The aim of this industry project is to improve the operation of the Multi-effect Evaporators at Pioneer Mill (near Ayr, North Queensland). This is part of an overall improvement in the operation of the co-generation plant at Pioneer Mill.

The control of sugar content (brix) in the syrup exiting the final evaporator in a set is very important. The current control of the brix suffers from periodic disturbances, as well as random disturbances causing wind-up oscillations. An example of previous disturbance responses in the final brix control is shown in Figure 3.

CDSC and CSR have devised several schemes for better control, mainly aimed at reducing the fast oscillatory disturbance effects. It was suspected that these fast oscillations would be reduced by reducing the interaction between the brix controller and the level controllers that are used in each evaporator. Applying a properly-tuned decoupler to the B set of evaporators has improved the sugar content control of this chain, in comparison to the A set. See Figure 4.

Subsequent visits to Pioneer Mill have resulted in the application of the decoupling scheme to both evaporator sets.
A.3 OPTIMISATION BASED OPERATOR GUIDANCE SCHEMES

Project Leader: J.H. Braslavsky

Researchers: D. Allingham, M. Downey (BHP-Billiton), B. Godoy (Student), G.C. Goodwin, K. Lau, J. Lee (BHP-Billiton), A. Maddever (BHP-Billiton), J. Truelove (BHP-Billiton) and R. Turner (BHP-Billiton).

This project has been carried out under the partnership of the Centre with BHP-Billiton Innovation (Newcastle), and deals with the development of new technologies using state-of-the-art model-based control and estimation tools. The project currently encompasses two Industrial Case Studies:

- Sferics reduction in electromagnetic mineral exploration,
- Modelling and control of copper heap bioleaching processes.

A.3.1 Sferics reduction in electromagnetic mineral exploration

The focus of this Industrial Case Study is the reduction of sferics noise in mineral exploration with GeoFerret, an Australian designed and developed electromagnetic exploration technique.

The reduction of sferics noise is central to the improvement of signal to noise ratio for the detection of deeper ore bodies. See CDSC Annual Report 2006 for more background information.

There have been important research outcomes in 2007 leading to new broadband (4 to 1500 Hz) noise cancellation techniques that uses spatial correlation of sferics noise. The noise cancellation has been applied to local nodes (on the exploration site) and is performed using a mathematical model of the earth and measurements from remote nodes (away from the exploration site).

Progress in 2007 has included:

- Development of earth models and noise cancellation techniques to minimise sferics noise in the frequency range 200 Hz to 1500 Hz. Sferics noise in this frequency range is typically non-stationary and arises mainly from near-field storm activity. Noise cancellation is performed using only vertical-field (Z to Z) measurements.
- Incorporation of estimation techniques that minimise model bias arising from the use of noisy input data (errors-in-variables problem).
- The arrival of new (lower noise) sensors allows the development of techniques to perform noise cancellation using horizontal and vertical-field (XY to Z) measurements.

The frequency range of noise cancellation has been extended to frequencies as low as 4 Hz, including now far-field, quasi-stationary sferics noise. Separate models are used for low and high frequency ranges.

Current work focuses on the development of a single, unbiased model for broadband multimode noise cancellation, and the implementation of code automating the model estimation and signal processing.

Figure 5: Power spectral densities of data measured with new sensors. Different colours correspond to measurements at different time epochs.

Left: horizontal Y-field. Right: vertical Z-field. Low frequency (far-field, quasi-stationary) sferics noise known as Schumann resonances can be seen on the left plot as a series of broad peaks approximately at frequencies 8 Hz, 14 Hz, 21 Hz, 27 Hz and 34 Hz. Higher frequency (near-field, non-stationary) sferics noise can be seen on the right plot as a mound around 200 Hz to 1500 Hz, with different power at different times due to non-stationarity. Harmonics of 50 Hz due to power supply noise are clear on both plots as narrow peaks at 50 Hz, 150 Hz, etc.
Figure 6: Estimated earth model validation by noise cancelling performance. Time series measured (raw) response $Z$, model-based estimated responses $Z_{\hat{X}}$ (from $X$ measurements only), $Z_{\hat{Y}}$ (from $Y$ measurements only), $Z_{\hat{X}Y}$ (from $XY$ measurements), and estimation error $Z-Z_{\hat{X}Y}$. Sferics appear as groups of impulsive disturbances standing out over the instrument noise baseline. We can see the effectiveness of the sferics noise cancellation technique by comparing the time series $Z$ (top) with the estimation error $Z-Z_{\hat{X}Y}$ (bottom).

Figure 7: Combined model noise cancellation performance: power spectral densities of raw measurements $Z2$, and residuals after sferics noise cancellation $Z2-Z2_{\hat{X}Y}$. Harmonics of 50 Hz were not removed. Significant attenuation is achieved for a broadband range of frequencies, 4 to 1500 Hz.
A.3.2 Modelling and control of copper heap bioleaching processes

The focus of this Industrial Case Study is the development of mathematical models for the control of heap bioleaching processes for the extraction of copper from sulphide minerals. Heap bioleaching is a metal extraction technology based on the slow dissolution of metals by percolation of a leaching solution through large heaps of crushed mine tailings. The technology shows great potential as a low cost alternative to smelting. See CDSC Annual Reports 2003-2006 for more background information.

The Case Study is the topic of research of PhD candidate Boris Godoy. The work of Boris appears to be the first in analysing the potential of modern feedback control techniques for the improvement of heap bioleaching technology, with promising results.

In September 2007, Boris submitted his PhD thesis, currently under examination. Highlights of the work done in 2007 include the following:

- Numerical implementation of BHP-Billiton’s simulator of the process to operate in feedback. This simulator is a high complexity, black-box mathematical model of the process originally designed to operate in batch mode. The feedback implementation was required to test feedback control strategies with Matlab.
- Development and numerical implementation of feedback control strategies based on low complexity linear incremental models fitted to the BHP-Billiton simulator. These control strategies include: internal model control and model predictive control.
- Parametrisation and numerical implementation of an extremum seeking feedback control strategy acting on heap aeration. This strategy is particularly appealing for a complex process such as heap bioleaching because it does not require a mathematical model of the process. Simulation results are promising.
- Simulation study of robustness to model uncertainties in the proposed feedback control strategies.

Figure 8: Simulation of a transient heap bioleaching response regulated using extremum seeking. Target process variable: copper concentration (top); manipulated variable: heap aeration rate (bottom). Extremum seeking adaptively brings the target process variable to its extremum value without requiring a model of the process.

Figure 9: Simulated total copper extraction with (ES) and without (nominal) extremum seeking feedback.
A.4 INTEGRATED MINE PLANNING (BHP-BILLITON)

Project leader: R.H. Middleton

Researchers: G.C. Goodwin, M.M. Zhang, M.M. Seron, C. Rojas (Student), T. Perez

This project is aimed at developing tools for optimisation of the Net Present Value (NPV) of open pit mines subject to uncertainty and constraints. The total mine planning could be posed as a single optimisation problem. This formulation, however, would result in a problem whose solution is intractable based on current capabilities of computational methods – the curse of dimensionality. In order to obtain practical solutions, this problem can be separated into different stages:

1. Finding the ultimate mine shape.
2. Discretise the mine into manageable blocks.
3. Forming aggregates of blocks according to some estimated properties.
4. Reshape the aggregates into phases enforcing constraints not previously considered when forming the aggregates.
5. Schedule the extraction mining of the different phases taking into account uncertainty in future metal price.

In 2007, CDSC focussed on two aspects of the problem. The first was the re-formulation of the mechanism used to generate scenarios for future metal price. The traditional approach consists of scheduling for maximising the NPV based on price scenarios generated via Monte Carlo simulations. In order to have a reliable description of the future behaviour, it is normally necessary to consider a large number simulations. Instead of following this approach, we have proposed to use a reduced set of likely scenarios. These scenarios are generated using carefully chosen approximations by discrete distributions of the underlying stochastic phenomena together with a temporal quantisation: Hinged Stochastic Interpolation (HSI).

Tests results have demonstrated that the use of the HSI method can improve the accuracy in the estimate of the mining project valuation using a small number of price scenarios compared to using the same number of price scenarios from Monte Carlo simulations. From these tests, we have also gained insights into how hinged points are to be chosen in order to obtain the best representative price scenarios.

A second aspect of mine planning investigated in 2007 was that of feasible phase designs, which is critical in a long-term mine planning process since it significantly affects NPV. BHP-Billiton uses a proprietary mine planning tool to perform the phase design. In order to simplify the problem, some of the constraints have been relaxed, and the solutions then need manual adjustment to satisfy practical mining requirements. To alleviate the need for manual intervention, we have developed an algorithm which performs perturbations to the current solution and seeks the optimum NPV while ensuring the practical mining requirements.
Figure 10: Hinged-interpolated Scenarios for the Copper Price 1974-1992 with the actual Copper Price (thick green line) and the closest fitted Scenario in a Mean-square Sense (black line).

Figure 11: Scatter plot of NPVs where the error bars show the interval between 1 standard deviation lines of the 10 sets of 27 MC simulations.

Figure 12: A practical mining phase design (plan view) generated by the automatic algorithm developed by CDSC vs. original solution. The red circles indicate the spots where the practical mining requirements are not satisfied in the original solution.
A.5 PERFORMANCE OPTIMISATION OF MARINE SYSTEMS (HALCYON INTERNATIONAL, HAMILTON JET, ROBOTIKER-TECNALIA)

Project leader: T. Perez

Researchers: G.C. Goodwin, J.-C. Agüero.

External Collaborators: T.I. Fossen (NTNU, Norway), P. Steinmann (Halcyon International, Australia), D. Borret (Hamilton Jet, New Zealand), R. Rodriguez-Arias (ROBOTIKER-Tecnalia, Spain)

Overview: Present day marine systems are designed to perform complex operations with appropriate reliability and economy. These requirements demand an interdisciplinary approach to address the tight integration of design aspects related to hydrodynamics, structures, and motion control.

This project started in late 2007 and is dedicated to the design of tools for guidance and motion control with the aim of optimising the performance of marine vehicles in different operations. The project targets vessels and operations within offshore, maritime transport, underwater exploration, unmanned vehicles and wave energy conversion. Some of the current research is being conducted together with international collaborators and industry affiliates.

A.5.1 Marine systems simulation tools

Researchers: T. Perez and T. Fossen (NTNU, Norway)

The Marine Systems Simulator (MSS) is an environment developed to provide the necessary resources for rapid implementation of mathematical models of marine systems with focus on control system design. The platform adopted for the development of MSS is Matlab/Simulink. This allows a modular simulator structure, and the possibility of distributed development. Openness and modularity of software components have been prioritised in the design, which enables a systematic reuse of knowledge and results in efficient tools for research and education.

This work is being done in collaboration with Prof. Thor Fossen from NTNU, Norway. The latest version of the software and future updates can be freely downloaded at www.marinecontrol.org

Figure 13: Marine Systems Simulator Autopilot Demo. This demo implements a PID heading autopilot controller for a mariner class cargo ship and uses a Kalman filter to extract the low frequency motion from the total motion, which includes motion due to the waves. For further details see www.marinecontrol.org
A.5.2 Identification of radiation force models of marine structures

Researchers: T. Perez and T. Fossen (NTNU, Norway)

The ability to predict ship responses and loads in waves is an important tool in the design of marine structures and motion control systems. One method for constructing time-domain models consists of using the data generated by the hydrodynamic codes to compute the different elements of the so called Cummins equation of ship motion. This equation contains convolution terms that describe fluid memory effects associated with radiation forces.

Due to the convolution terms, the models based on the Cummins equation are inconvenient for analysis and design of control systems as well as for simulations in standard packages like Matlab/Simulink. Therefore, in this project we have been studying different identification methods in both time and frequency domain to make best use of the available hydrodynamic data and replace the convolutions in the Cummins equation.

In 2007, we compared different identification methods already proposed in the literature in terms of accuracy of the estimates, complexity of implementation, and ease of use. Our findings indicate that frequency-domain methods based on regression are the most suitable. Also, we determined the structure of the minimum order model that satisfies all the properties derived from the hydrodynamics: stability, passivity, low frequency limits and relative degree.
A.5.3 Experiment design for identification of vessel dynamics
Researchers: T. Perez, G.C. Goodwin, J.C. Agüero and D. Borret (Hamilton Jet, New Zealand)

The structure of mathematical models of marine vessels can be obtained from first principles modelling, however, the parameters often need to be estimated from trials. The ability of an estimation method to produce good estimates of the parameters depends on how much information about the dynamics of the system is contained in the data used for obtaining the estimates. This project examines the design of optimal experiments for vessels performing different operations: dynamic positioning, manoeuvring at low speed, manoeuvring at high speed.

In 2007, we focused on a two-stage approach: first, collect data from step responses; second based on the information gathered, design appropriate signals for parametric model identification.

A.5.4 Gyroscopic stabilisation of marine platforms
Researchers: T. Perez and P. Steinmann (Halcyon International, Western Australia)

The use of gyroscopic effects for the roll stabilisation of marine structures was proposed over 100 years ago. This approach was very effective, but limited control and large sizes hindered further developments. In recent years there has been significant interest in revitalising gyro stabilisers due to improvements in materials, bearings, and lubricants, which have contributed to fast spinning devices and size reduction. In addition, fast and reliable computer control systems ensure adequate operation over an envelope of sailing conditions.

This project has examined methods for determining the size of the gyros to achieve a desired roll reduction and also to the control design to ensure performance in a range of sailing conditions. In 2007, we have developed a simulation tool GyroSim, which allows a rapid evaluation of the expected performance of gyro stabilisers. Also, we have proposed an adaptive scheme to maximise performance in changing environmental conditions.

Figure 16: Halcyon Twin gyro-stabiliser

Figure 17: Simulation of a predicted roll performance for a patrol vessel using GyroSim. In this figure we can see the roll angle, rate and acceleration for the vessel with and without the gyro stabiliser. A reduction of 87% in roll angle (RMS) is predicted.
A.5.5 Improvement on ride control for high-speed vessels
Researchers: T. Perez and P. Steinmann (Halcyon International, Western Australia)

Ride control of high-speed vessels refers to the reduction of wave induced motion in roll and pitch while at the same time, providing adequate trim and heel. These control objectives are achieved using combinations of different actuators depending on the type of vessel: trim flaps, interceptors, stabilising fins, and T-foils. According to the location of these actuators on the hull, they can produce forces affecting either roll or pitch motion, or both. Therefore, the control allocation for the different actuators becomes a key factor in changing sailing conditions (speed and heading).

In this project, we have been examining the control allocation of the different actuators. In 2007, we developed a novel adaptive control allocation strategy to optimise the control forces produced by each actuator in changing sailing conditions. This allocation, together with other features, were added to Halcyon’s existing ride control system.

The features added improved the performance and contributed towards Halcyon winning a contract for the upgrade of the Bay Class patrol boats of the Australian Customs Service. See the outcomes section of the Annual Report for further details.

A.5.6 Identification of a time-domain hydrodynamic model of a prototype hull for a wave energy converter
Researchers: T. Perez and R. Rodriguez-Arias (ROBOTIKER-Tecnalia, Spain)

A search for renewable energy resources has revitalised the interest in devices for wave energy conversion. Wave energy converters (WEC) extract energy from the motion induced by the waves on particular hull designs. In order to maximise the extracted energy, the design of a control to regulate the loads of the power take off element is of great importance. In order to design such control systems, it is necessary to have a good mathematical model of the hydrodynamic part of the converter.

In this project, we address the modelling of the complete WEC system and design optimal control strategies for maximum energy extraction using prediction techniques together with constrained control optimisation.

In 2007, we identified time-domain models of two hull prototypes of a WEC based on frequency domain data obtained from hydrodynamic codes, and validated the models based on experimental data. The models obtained helped ROBOTIKER-Tecnalia to decide on the preferred hull and provided the basis for the prediction of the energy absorbed by the device. These models will be used as a basis for developing the control strategies.

Figure 18: The Bay Class Australian Custom Vessels are now fitted with Halcyon’s ride control system developed in collaboration with CDSC. Image courtesy of the Australian Customs Service. Copyright Australian Customs Service.

Figure 19: Model validation using scaled-model experimental data of a pitch decay test in calm water of a hull for a wave energy converter.
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.

B.1 CONTROL OF SELF-SERVO WRITING PROCESS FOR NANO-SCALE POSITIONING IN A MEMS-BASED SCANNING PROBE DATA STORAGE SYSTEM

Researchers: S.O.R. Moheimani, in collaboration with: A. Sebastian, A. Pantazi, H. Pozidis and E. Eleftheriou

MEMS-based scanning-probe data storage devices are emerging as potential next-generation ultra-high-density data storage systems. A Probe storage device uses nanometer-sharp tips, typically used in scanning probe microscopes to write information to and read the recorded information from a storage medium; see Figure 20 for Schematics of the IBM’s prototype probe-based storage device are illustrated in. This device is based on a thermomechanical principle for storing and retrieving information written on thin polymer films. Digital information is stored by making indentations on the thin polymer film by using the tips of AFM micro-cantilevers, which are a few nanometers in diameter. The shape of a typical indentation resembles an almost conical structure with diameter of approximately 15 to 30 nm. This indentation shape results in an error rate performance that rapidly deteriorates as the probe-tip distance from the centre of the indentation increases.

In this system, a MEMS-based micro-scanner with two dimensional motion capabilities is used to position the storage medium with respect to the array of read/write probes. Displacement in each direction is measured by a thermal position sensor. High precision positioning is a key component of such systems required for navigating the read/write probes above the storage medium. To achieve repeatable positioning over a large storage area, media-derived position information needs to be written on the storage medium first. Dedicated servo-fields are employed to obtain media derived position information. Precise writing of these servo fields using a global position sensor poses unique control challenges. This is mainly due to the fact that the global position sensor is susceptible to low-frequency drift.

During this project a control architecture based on resonant controllers was designed and implemented such that the impact of measurement noise on positioning accuracy of the micro-scanner was minimal. The controller also provided improved damping, illustrated in Figure 21, and hence resulted in satisfactory tracking performance. Experimental results on a scanning-probe data storage device demonstrated a positioning accuracy of 0.21 nm.
B.2 TRACKING CONTROL OF A NANOPositionER USING COMPLEMENTARY SENSORS

Project Leader: S.O.R. Moheimani

Researchers: I. Mahmood (Student) and K. Liu

Piezoelectric tube scanners are widely used in Atomic Force Microscopes (AFMs) for nanoscale positioning. In the past piezoelectric tube scanners were operated in open loop. However, there has been increasing interest in operating them under feedback control to achieve better positioning accuracy. Performance of a feedback-controlled piezoelectric tube scanner is limited by its inherent nonlinear properties such as hysteresis and creep, its mechanical resonant modes, the bandwidth of its displacement sensors and the noises associated with the sensors.

Capacitive sensors have emerged as the displacement sensor of choice in AFMs. Resolution of a capacitive sensor is largely determined by its bandwidth and the spectral density of its noise, which is typically in the order of 20 pm/√Hz for a 100 micro m range. Consequently, to achieve sub-nanometer resolution, the sensor’s bandwidth needs to be made small, 100Hz in this case. Achieving satisfactory tracking performance using a low-bandwidth displacement sensor is a challenging task. To alleviate this, the piezoelectric strain voltage signal induced in the electrode opposite to the actuating electrode is used as a secondary displacement measurement. Noise spectral density of this signal is about a thousand times less than the capacitive sensor measurement. In this project, H inf control design approach has been employed to synthesise a dual-loop feedback controller that utilises both measurements over two complementing frequency ranges to track a triangular waveform input. The schematics of the proposed feedback control scheme are illustrated in Figure 22.

![Figure 22: Schematics of the proposed feedback control system](image-url)
Experimental results demonstrate a significant increase in the tracking bandwidth due to the use of the additional sensor and excellent tracking performance at high speed scans. By inspecting the frequency response plots in Figure 23, we conclude that the closed-loop system has a bandwidth of 310 Hz. This is about three times higher than the bandwidth of the capacitive sensor alone, and is due to the inclusion of strain voltage signal as a secondary measurement. A damping of 20 dB at the first resonant mode is also evident from the frequency response plots. Figure 24 illustrates the open and closed-loop time responses of the nanopositioner due to 5, 20 and 40 Hz triangular input signals. It can be observed in closed-loop that the controller successfully damps the induced vibrations and provides excellent tracking performance, particularly at low frequencies. At the slow speed scan of 5 Hz the controller displays excellent tracking performance with RMS tracking error of only 1.9 nm, i.e. 0.06% of the entire scan range. The tracking error remains satisfactory even as the scan frequency is increased as high as 40 Hz. The error does not exceed 0.25% of the scan range.

Figure 23: Experimentally obtained closed-loop frequency responses of $T_{ix}(i\omega)$ (solid), $T_{dx}(i\omega)$ (dash) and open-loop frequency response $G_{yx}(i\omega)$ (dash-dots).

Figure 24: Open-loop (left) and closed-loop (right) time response plots of 5 Hz, 20 Hz and 40 Hz scan.
B.3 PHYSICAL-MODEL-BASED CONTROL OF A PIEZOELECTRIC TUBE

Project leader: S.O.R. Moheimani.

Researchers: P. J. Gawthrop and B. Bhikkaji

The process of scanning in many Scanning Tunneling Microscopes and Atomic Force Microscopes is performed by actuating a piezoelectric tube, Figure 25. The piezoelectric tube has to be actuated in a raster pattern with precision and speed for good scans.

Figure 25 Illustration of the experimental setup

Dynamics of piezoelectric tubes can be well approximated with linear models when actuated using signals obtained by regulating charges as opposed to voltages. In the set up used here, Figure 25, the electrode on one side of the tube is used for actuation and the electrode on the opposite side is used for sensing. It turns out that this asymmetric non-collocated actuation gives raise to a linear model, Figure 26, with significant non-minimum phase behaviour. The linear model also reveals the presence of a low frequency resonant mode which causes mechanical vibrations by amplifying the frequency components of the reference signal that lie close to it, Figure 27.

Figure 26 Frequency response functions of the piezoelectric tube
Application of physical model based control method (PMBC) is normally restricted to minimum phase plants. These control methods are described in terms of bond graphs, Figure 28. In this project PMBC methods have been extended to non-minimum phase plants in general. In particular, they have been applied to a piezoelectric tube to damp its first resonant mode. The idea behind this control design methodology is to use the classical idea of attaching a mass spring damper, tuned to the resonance frequency of the system, and extract the energy out of the system. A damping of 25 dB of the resonant model has been achieved using this control design, Figure 26; thus enabling a vibration free actuation of the tube.

Figure 27: (a) Open loop; and (b) Closed-loop response of the piezoelectric tube to a 5.5 μC, 40Hz triangular waveform reference signal.

Figure 28: Physical Model Based Control.
(a) The ideal collocated case
(b) The practical case where actuator and sensor dynamics are represented by the transfer system
B.4 OPTIMAL INPUT SIGNALS FOR BAND-LIMITED SCANNING SYSTEMS

Researchers: A.J. Fleming and A.G. Wills

Many scientific and industrial machines contain mechanical scanners driven with periodic trajectories. For example, beam steering scanners, manufacturing robots, cam motion generators, and scanning probe microscopes. Without knowledge of system dynamics, this project aims to design periodic input signals that maximise the speed and accuracy of band-limited scanners. The focus is on design of input signals for scanning probe microscope nano-positioning stages.

The foremost problem associated with driving resonant mechanical systems with wide-bandwidth signals is illustrated in Figure 29. High-frequency input components excite structural resonances resulting in output ripple. This can be reduced by simply filtering the input, but the smoothing effect severely degrades scan linearity. As an alternative, we have proposed a quadratic optimisation where part of the signal is fixed as linear in the time domain and the remainder is optimised in the frequency domain to reduce harmonic content above a certain frequency. The resulting signal provides perfect scan linearity with minimal harmonic power. The required optimisation has an analytic solution and has been packaged into a toolbox for ease of use.

Experimental results taken from a Physik Intrumente P-734 nano-positioner are shown in Figure 30. The optimal signal exhibits improved scan accuracy with no requirement for hardware improvement or feedback. An estimate of the system’s lowest resonance frequency is the only required design parameter.

Figure 29: This diagram illustrates a major problem that occurs in mechanical scanners and machinery. The time- and frequency domain representation of a triangle scanning reference is shown on the left hand side. When applied to a resonant mechanical system, the wide-bandwidth input excites structural resonances to cause output ripple. This project aims to mitigate output ripple by reducing input bandwidth without compromising scan linearity or speed.

Figure 30: Experimental scanning trajectories recorded from a Physik Intrumente P-734 nano-positioner. The scan frequency is 20 Hz while the first mechanical resonance occurs at 420 Hz. The top trajectory results from a triangle wave input, followed by a filtered triangle, shaped triangle, minimum acceleration trajectory and finally the optimal trajectory. The scan error in the optimal trajectory is 0.18% RMS compared to 2.9% RMS for the triangle signal. The optimal trajectory provides better performance than all present techniques with improved robustness due to the absence of model-based design.
B.5 MINIMISING SCANNING ERRORS IN PIEZOELECTRIC STACK ACTUATED NANOPositionING PLATFORMS

Project leader: S.O.R. Moheimani
Researchers: S.S. Aphale and B. Bhikkaji

As we enter the age of miniaturisation, the performance of nanomachinery is of ever-increasing importance. Nanopositioning is a key technology that impacts a range of important fields, including nanomachining, scanning probe microscopy, microlithography and nanometrology. There is an ever-present demand for nanopositioning systems that operate with higher resolution, greater accuracy, higher scanning speeds and a larger range of motion.

Piezoelectric stack-actuated nanopositioning platforms, see Figure 31 for an illustration, are known to offer larger scan ranges with greater mechanical robustness and lower cross-coupling between the axes. These platforms can also be easily integrated with existing scanning microscopes, leading to a significant body of research aimed at improving their overall performance.

In this project a Polytec PI-734 nano positioning platform has been considered, Figure 31. This platform can scan an area of 100 micro m x 100 micro m. Nonlinearities inherent to the piezoelectric stack actuators and resonant modes due to their mechanical construction are the two main factors limiting the performance of this platform. Linear models fitted for the nanopositioning platform reveal the presence of a resonant mode, Figure 32. This resonant mode amplifies the harmonics of the reference signal leading to a distorted output. Controller design methodologies such as Positive Position Feedback, Polynomial based pole-placement and Resonant Control were used to design controllers to damp the resonant mode. Damping of the resonant mode prevents the amplification of the harmonics. The effectiveness of the control designs in being robust to modelling errors was tested.
It was found that polynomial based control design was the best suited for the nanopositioner. It not only achieved a 23 dB damping at the resonance, it was also more robust to modelling errors and high frequency noises. It was further shown that superior tracking performance could be achieved by combining this controller with an Integral controller. This was demonstrated by tacking a 4 Hz 80 micro m x 80 micro m raster scan with a resolution of 62.5 nm, Figure 33. Noise analysis suggests that a resolution of 8nm is achievable.
B.6 DESIGN OF MODULATED AND DEMODULATED CONTROLLERS FOR FLEXIBLE STRUCTURES


We have developed a novel method for controlling vibrations within a resonant structure equipped with piezoelectric transducers. The scheme uses a parallel connection of modulated and demodulated controllers, each designed to damp the transient oscillation corresponding to a single mode. This technique allows multiple modes to be controlled with a single actuator. Experimental results obtained from a piezoelectric laminate cantilever beam have confirmed the theoretical analysis - see Lau, Quevedo, Vautier, Goodwin and Moheimani (2007) in Journal Papers.

B.7 ROBOTICS RESEARCH

Researchers: M. Quinlan, P. Baker, S. Chalup, R. Fisher, N. Henderson (Student), R. King, J. Kulk (Student), R.H. Middleton, S. Nicklin (Student), O. Obst, P. Turner, J. Welsh, M. Willis

A new prototype robot platform, the robot ‘bear’, capable of both quadrupedal and bipedal motion has been developed in conjunction with the local company Tribotix. The bear required extensive development of hardware, sensors, software and mechanical design, and was selected as one of 4 tenders considered at RoboCup 2007 as the new robot to replace the Sony Aibo in the new RoboCup Standard Platform League. The bear includes high performance servo motors, an efficient yet powerful geode processor, and an extensive array of sensors suitable for a range of applications. Although not chosen for the standard platform league in 2008, the bear has had some initial sales to robotics research labs in Ireland and in Australia.

Oliver Obst participated in the 3D Simulation League of Robocup 2007 as part of a joint University of Newcastle and Technical University of Freiburg team. Oliver achieved first place in the international competition held in Atlanta during July 2007.

In the 2007 RoboCup Soccer four legged league team, the NUbots achieved 2nd place in Atlanta. A range of improvements in this years software included implementation and testing of multiple model (mixture) Kalman filter techniques for localisation. These are important for dealing with ambiguous information such as field lines and other markings, and have been implemented and tested for the 2007 code. These are becoming increasingly important as location cues as other objects, such as colour coded beacons are removed from the field.

Classification of the robot’s image of the field was partially automated, using Gaussian mixtures of the hue dimension of HSI space. This vastly reduced the amount of time required to tune the robot’s vision to a new competition venue. Recent research has focussed on fitting multivariate Gaussian mixtures to the full three dimensional HIS space, to allow addition cues from colour saturation and intensity to be used in classification.
**C. CONTROL SYSTEM DESIGN**

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

**C.1 VIRTUAL LABORATORIES**

Researchers: G.C. Goodwin, A. Bastiani, F. Sobora, E. Silva (Student), P. Wellstead (Hamilton Institute, Maynooth, Ireland), O. Rojas (University of NSW, Sydney)

**Overview:** This project has been on-going for several years. The laboratories capture many of the real world design case studies carried out by CDSC researchers. A full description of the laboratories is available at: www.virtual-laboratories.com

Virtual Laboratories for Process Control Design (VLPC) provides an on-line solution to the traditional “physical” experimental laboratories undertaken for process control engineering concepts. The VLPC virtual software model allows the student to self-pace these laboratories by applying the process control theory learnt in their studies to this simulated environment. This software tool has been developed based on real world process control situations. The Laboratories can be used by undergraduate students within universities as well as by working engineers. The software tool allows students to access the laboratories at a time which suits their study needs.

The VLPC product is being commercialised by the University of Newcastle’s commercial arm – TUNRA Ltd.

The experiments fall into two categories, namely

- Copies of classroom scale experiments (e.g., servo kits, coupled tanks, etc.)
- Laboratories based on realistic practical systems (e.g., rolling mills, steel casting machines, paper machines etc.).
C.2 APPLICATIONS OF OPTIMISATION IN ESTIMATION AND CONTROL

Researchers: G.C. Goodwin, M.M. Seron and D.Q. Mayne (Imperial College)

Advanced design aims to achieve the best possible performance subject to operational constraints. Such questions can be formulated as optimisation problems. The advantages of using an explicit optimisation formulation include clear articulation of performance trade-offs and the provision of a clear basis for quantitative comparison of different strategies. We have deployed these tools in scheduling, estimation and control. We have also studied many practical case studies of the ideas drawn from the mining, mineral and metal processing field – see Goodwin, Seron and Mayne (2007) in Plenary/Keynote Addresses.

C.3 SAMPLED DATA MODELS FOR LINEAR AND NONLINEAR SYSTEMS

Researchers: G.C. Goodwin, J.I. Yuz (Universidad Técnica Federico Santa María) and M.E. Salgado (Universidad Técnica Federico Santa María)

In this project we have investigated several aspects of the relationship between zero dynamics of sampled-data models for linear stochastic systems and sampled-data models for nonlinear stochastic systems. Particular emphasis has been placed on a special class of approximate sampled-data models which share the same zero dynamics as linear systems of the same relative degree – see Goodwin, Yuz and Salgado (2007) in Conference Papers.

C.4 ROBUST MPC

Researchers: C. Løvaas (Student), M.M. Seron and G.C. Goodwin

For open-loop stable systems having input constraints and unstructured model uncertainty, we have developed a new closed-loop stability test applicable to typical output-feedback model predictive control (MPC) policies. The new stability test is less conservative than previous proposals, and enables both analysis and synthesis of input-constrained MPC policies. In particular, we have proposed a robust MPC design which minimises a quadratic upper bound on a nominal cost function in each step. The upper bound is determined off-line subject to the stability test using convex optimisation. Simulation results show that the proposed design can be much less conservative than robustly stable designs based on conventional cost functions – see Løvaas, Seron and Goodwin (2007a) in Conference Papers.

Figure 35: Simulation Result
C.5 CONSTRAINED CONTROL AND ESTIMATION

C.5.1 Dynamic programming solution to constrained MPC

Researchers: J.A. De Doná and J.B. Mare (Student)

This project has investigated the use of dynamic programming techniques for finding optimal control laws for constrained linear systems. Typical problems considered involve a quadratic cost functional to be minimised over a horizon of length N subject to the satisfaction of linear constraints. Global solutions (i.e., valid in the entire state space) for these problems, and for arbitrary horizons, have been derived analytically by using dynamic programming. Alternative solutions to these problems have been reported recently in the literature, for example, approaches that use the geometric structure of the underlying quadratic programming problem and approaches that use multi-parametric quadratic programming techniques. The solution by dynamic programming investigated in this project coincides with the ones obtained by the aforementioned approaches. However, since our solutions have been derived using a different approach exploiting the dynamic nature of the constrained optimisation problem, the results obtained in this project complement those of previous methods and reveal additional insights into the intrinsic structure of the optimal solution.

C.5.2 Connections between constrained control and estimation problems

Researchers: G.C. Goodwin, J.A. De Doná, M.M. Seron, C. Müller, J.B. Mare (Student), Xiang W. Zhuo (student)

This project has investigated the connections and symmetries between two important problems in systems theory and applications; namely, control and estimation. Particular emphasis has been given to the connection between these problems in the presence of constraints, where very few results are known to date. One of the results obtained in this project has been to derive the Lagrangian dual of a constrained linear estimation problem, where the resulting dual problem is a linear optimal control problem with projected cost variables. The symmetry between the primal constrained estimation problem and the resulting dual optimal control problem is revealed when the primal problem is expressed in an equivalent form involving projected variables. This project has also revealed a different kind of symmetry relationship between constrained output reference tracking and constrained state estimation problems. The latter symmetry, which is different from the traditional duality relationship between control and estimation, provides a complete translation of all variables of one horizon into the variables of the other. The symmetry relationship leads to interesting interpretations of several of the resulting optimal trajectories.

C.5.3 Constrained nonlinear model predictive control

Researchers: J.A. De Doná, M.M. Seron, J. Rammage (University of Wollongong), J.B. Mare (student), H. Haimovich (Universidad Nacional de Rosario, Argentina), M. Lazar (Eindhoven University of Technology, The Netherlands)

Partially funded by University of Newcastle RGC Strategic Pilot Grant G0186681 and CDSC.

This project has investigated a framework for dealing with certain classes of constrained nonlinear model predictive control (MPC) problems which consists in solving a quadratic programming (QP) optimisation at each sampling time. This feature broadens the applicability of nonlinear MPC since many efficient tools for solving QP problems (both numerical algorithms and explicit solutions) are available. One of the contributions has been to show that the optimal control sequence for a nonlinear system of certain features, with a quadratic cost and linear inequality constraints can be computed in exact form via QP provided the optimisation horizon is no larger than a critical quantity that we name the “input-output linear horizon.” In addition, the issue of input to state stability (ISS) with respect to disturbance inputs has been investigated. One proposed solution consists of incorporating a set of extra linear inequality constraints into the QP to guarantee ISS. Thus, the resulting constrained nonlinear MPC scheme has two very attractive properties; namely, simplicity of the solution and guaranteed stability and robustness.

C.5.4 Explicit error estimation in suboptimal constrained control problems

Researchers: J.A. De Doná and C. Müller

This project has studied different approximations to constrained linear quadratic control problems, including discrete-time sampled-data approximations. Explicit estimates for the error in the performance index rendered by the approximated solutions have been investigated. These error estimations can be used to evaluate the level of sub-optimality of the sampled-data solution that corresponds to a given length of the discretisation interval, or to compute a discretisation interval length that guarantees a given error of approximation.

C.6 NONLINEAR CONTROL

C.6.1 Theory of nonlinear control systems

Researchers: J.A. De Doná, M.M. Seron, J. Levine (Ecole des Mines de Paris, France) J. Rammage (University of Wollongong), H. Haimovich (Universidad Nacional de Rosario, Argentina)

Partially funded by University of Newcastle RGC Strategic Pilot Grant G0186681 and CDSC.

This project has studied different aspects of the theory of nonlinear control systems, including open problems in Differential Flatness; the use of concepts of Differential Flatness in Model Predictive Control of Nonlinear systems; and the Differential Vector Space approach.

Special attention has been given, in connection with these concepts, to particular structures of nonlinear systems to achieve simplifications in the online control computations.

Some details of this project are available in the following internal report:

C.7 QUANTISED CONTROL
Researchers: M.M. Seron, G.C. Goodwin and H. Haimovich (University of Rosario, Argentina).

This project deals with quadratic stabilisation of discrete-time systems with quantisers. In previous years we have obtained an explicit geometric characterisation of quadratically stabilising state feedback laws that are based on the use of multivariable quantisers of minimum dimension. This characterisation consists of a set of necessary and sufficient conditions for a quantised static state feedback to render a given quadratic function a Lyapunov function for the closed-loop system. The framework is based on analysing the partition induced on the state-space by a quantiser and has allowed us to derive new results on minimum quantisation density for single-input systems, as well as to rederive well-known results from a different standpoint.

Using the geometric characterisation, we have also developed a systematic design procedure for finite-density quadratically stabilising quantisers for multiple-input (MI) systems. The resulting quantisers have a simple geometric structure and can be implemented via simple function evaluations. To the best of our knowledge, no such design of finite-density quadratically stabilising quantisers has been previously proposed in the literature for general MI systems.

We have also revisited the problem of minimisation of quantisation density, which is still an open problem for MI systems. Our contribution in this regard is to partially derive the structure that a quantiser that minimises density for a MI system should have. Our results reveal that the search for minimum density quantisers that map the state space into the input space is reduced to a search over quantisers that map the input space into the input space.

C.8 SYSTEMATIC COMPUTATION OF ULTIMATE BOUNDS FOR PERTURBED SYSTEMS
Researchers: M.M. Seron, E. Kofman (University of Rosario, Argentina), H. Haimovich (University of Rosario, Argentina), F. Fontanilla (University of Rosario, Argentina).

In this project we have developed a systematic method to compute ultimate bounds for both continuous- and discrete-time perturbed systems. The method is based on a componentwise analysis of the system in modal coordinates and thus exploits the system geometry as well as the perturbation structure without requiring calculation of a Lyapunov function for the system. The main features of the method are its systematic nature, whereby the required steps can be readily computer coded, requiring no adjustment of any parameters for its application, and its suitability for dealing with highly structured perturbation schemes, whereby the information on the perturbation structure can be directly incorporated. Examples have shown that the proposed systematic method may yield bounds that are tighter, or at least not worse than, those obtained via standard Lyapunov analysis employing quadratic functions.

We have employed the method described above to develop a novel systematic procedure to obtain componentwise ultimate bounds in perturbed sampled-data systems, especially when the perturbations arise due to quantisation. We have also combined the method with a technique for eigenvalue/eigenvector assignment by state feedback in a new control design algorithm for perturbed multiple-input systems. The new algorithm is systematic in nature and guarantees any desired componentwise ultimate bound on the state for systems with various types of uncertainties, including uncertain time-delays in the feedback loop.

We have recently extended the results to a class of perturbed feedback linearisable nonlinear systems with matched perturbations. For these systems, we have developed a systematic design procedure to compute a state feedback control that ensures a prescribed ultimate bound for the closed-loop system states. The procedure combines nonlinear state feedback linearising control with a state-feedback matrix computed via the eigenstructure assignment method mentioned in the paragraph above.

C.9 FAULT TOLERANT CONTROL

C.9.1 Switching strategies for sensor fault tolerant control
This sub-project is partially funded in 2008 by the ARC discovery grant DP0881419: “Fault tolerant multisensor feedback control”. In 2006 we reported a new paradigm for sensor fault tolerant control (FTC). This new paradigm consists of using a switching mechanism which selects, at each instant of time, a suitable sensor-estimator pair that achieves the best value of a performance optimisation criterion. A key element of the proposed FTC switching strategy is the computation of invariant sets where the variables that affect the optimisation criterion evolve under healthy and failed operation. The computation of these sets uses ultimate bounds of system trajectories and relies on the knowledge of different bounds on sensor noises under healthy and faulty operation and bounds on the reference signals and process disturbances. Conditions were provided such that the switching optimisation criterion (combined with the aforementioned invariant sets) automatically discards faulty sensors in the presence of at least one healthy sensor. In addition to this “implicit” FTC property, the proposed scheme is mainly aimed at maintaining high performance of the system during normal (fault-free) operation. The control is designed for a single control performance objective, that is, using the same feedback gain for all sensor-estimator pairs.
We have recently extended the strategy in two different avenues. The first extension consists of allowing for the use of different feedback gains according to the desired performance for each independent loop. That is, it is assumed that each controller has been designed according to the nature of the corresponding loop disturbances, sensor noises, available bandwidth, uncertainties and actuation constraints. A new stability proof using multiple Lyapunov functions was required for this case. As a second extension, we have revisited the closed-loop stability conditions based on invariant sets and have reduced the conservatism of the assumptions by refining the computation of these sets for healthy/faulty functioning. Indeed, we have developed arbitrarily close approximations of minimal robust positive invariant sets and adapted these approximations to the different operating regimes of the multisensor switching scheme.

**C.9.2 Sensor fault tolerant control of induction motors**

We have investigated the adaptation of the multisensor switching control strategy for fault tolerant control of induction motors. The proposed strategy combines three current sensors and associated observers that estimate the rotor flux. The estimates provided by the observers are compared at each sampling time by a switching mechanism which selects the sensors-observer pair with the smallest error between the estimated flux magnitude and a desired flux reference. The estimates provided by the selected pair are used by a field oriented controller to implement the control law. Pre-checkable conditions are derived that guarantee fault tolerance under an abrupt fault of a current sensor. These conditions are such that the observers that use measurements from the faulty sensor are automatically avoided by the switching mechanism, thus maintaining good performance levels even in the presence of a faulty sensor. Adaptation of the scheme for use in combination with direct torque and flux control of induction motors is the subject of current research.

**C.9.3 Actuator fault tolerant control**

This project was inspired by the aforementioned results on fault tolerant multisensor switching control. However, the actuator fault tolerant problem has posed a different set of challenges with respect to its sensor fault tolerant counterpart, since the plant mixes the effects of actuator malfunctions as observed from the system output.

We have thus developed an actuator fault tolerant control strategy based on invariant set computation. The proposed scheme employs a bank of observers which match the different fault situations that can occur in the plant. Each of these observers produces an estimation error with a distinctive behaviour when the observer matches the current fault situation in the plant. With the information of the estimation errors from each of the considered observers, a fault diagnosis and isolation (FDI) module is able to reconfigure the control loop by selecting the appropriate stabilising controller from a bank of precomputed control laws, each of which being related to one of the considered fault models. The decision criteria of the FDI is based on the computation of invariant sets of the estimation errors for each fault scenario and for each control configuration. We have derived conditions for the design of the FDI module and for fault tolerant closed-loop stability. Application of the strategy to course keeping in ship motion control is currently under investigation.

A preliminary version of the scheme was applied to achieve diagnosis and a fault tolerant control for a simulated active suspension system. Although lacking fault tolerant guarantees, this heuristically designed scheme was able to detect and identify an actuator fault and reconfigure the controller in order to maintain ride comfort and vehicle performance in the presence of road disturbances.

**C.10 DISSIPATIVITY APPROACH TO ROBUSTNESS IN CONSTRAINED MODEL PREDICTIVE CONTROL**

Researchers: C. Lavaas (Student), M.M. Seron and G.C. Goodwin

In this project, we have developed a novel closed-loop stability test applicable to a broad class of model predictive control (MPC) policies for discrete-time systems having model uncertainty described by given sum quadratic constraints. We believe that the proposed stability test is well suited for both analysis and design. In particular, robust closed-loop stability can be ensured by choosing the cost function parameters and the constraints in the MPC algorithm so as to satisfy, respectively, a linear matrix inequality condition and a set invariance condition – see Lavaas, Seron and Goodwin (2007b) in Conference Papers.

**C.11 LIMITATIONS IN FEEDBACK CONTROL OVER COMMUNICATIONS CHANNELS**


Research in the area of performance limitations in feedback control imposed by communications constraints has continued in a number of areas. For the case of additive white Gaussian noise (AWGN) communications channels, many information theoretic results are available, including the famous Shannon results on capacity. For additive coloured Gaussian noise (ACGN) channels, the information theoretic results available are more limited. General results on the capacity of a channel with feedback are not known. Recently, (Kim, Trans. On Information Theory, July 2006), has given a method for computing the capacity of a 1st order moving average (MA1) coloured Gaussian noise channel, \(1 + \alpha z^{-1}: \alpha \in (-1, 1)\).
Recently, we have been able to establish that for the case of a 1st order unstable plant, \( x_{t+1} = \phi x_t + u_t \), with an MA1 ACGN channel, stabilisation by a class of linear time varying controllers is possible if and only if the feedback channel capacity, \( C_{FB} \), satisfies \( C_{FB} \geq \log_2 | \phi | \).

Previously, much of the research in signal to noise ratio limited control has focussed primarily on stabilisation issues. More recently, we have begun examination of performance issues in signal to noise ratio limited control. For the case of a plant subject to a stochastic disturbance, we have been able to extend previous information theoretic arguments to give lower bounds on the achievable performance for any causal non-linear feedback over an AWGN channel.

\[
\lim_{k \to \infty} \mathbb{E}[\| x_k \|^2] \geq m \| \Sigma \|^{1/2} \left( 1 - e^{2C/2} \prod_{i=1}^{m} | \phi_i |^{1/2} \right)^{-1}
\]

In general, it is unclear whether these bounds are achievable. However, at least in the case of a 1st order plant (\( m=1 \)) with stochastic input disturbance, it can be shown that the lower bound on performance is achievable via an appropriate combination of static linear pre and post channel compensators.

More general problems, of higher order than 1, generally require more complex treatment, and static compensation techniques will not be optimal. In addition, it is unclear whether non-linear compensation techniques may offer some performance advantages. Current research is examining the interplay of estimation versus control objectives over AWGN channels in these more general contexts.

C.12 PERFORMANCE LIMITATIONS IN DISTRIBUTED CONTROL SYSTEMS

Researchers: R.H. Middleton and J.H. Braslavsky

Recent work on performance limitations in CDSC has examined questions relating to a class of distributed control problems. The particular class analysed gives rise to a chain of dynamic systems, with local feedback, and where the local performance is required to satisfy a type II servomechanism response, that is, achieve asymptotically perfect regulation, despite ramp type disturbances. This class of problems arises in diverse applications including Intelligent Vehicle Highway Systems, Irrigation Channel System flow regulation, and supply chain management.

It has long been known that under certain circumstances, such systems give rise to an effect known as ‘string instability’, or the ‘bullwhip’ effect, whereby, disturbances are amplified as they propagate down the string. A number of fixes for this problem have been proposed in the literature, and fundamental analysis of causes has been examined in some special cases. In this line of research, we extend this analysis to consider non-type II systems, heterogeneous strings, and strings with limited range communications.
D. SIGNAL PROCESSING

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. However the aim of this Program is to promote applications of modelling, control and estimation in various signal processing problems.

D.1 FUNCTIONAL ANALYSIS APPROACH TO SUBBAND SYSTEM APPROXIMATION AND IDENTIFICATION

Researcher: D. Marelli

The subband system identification method consists in identifying a linear system in the time-frequency domain. This technique can be also used to approximate a linear time-invariant system in the same domain. More precisely, by the composition of an analysis filterbank, followed by a (usually diagonal) transfer matrix and a synthesis filterbank. In both cases, it has the advantage of having a very high numerical efficiency. However, analysing such techniques is non-trivial and the best setup for subband system approximation and identification is not clear. In this work we proposed a functional analysis setting to the analysis of the subband technique, which lead us to results on both, subband system approximation and identification. Concerning system approximation, we have provided an analytical expression to calculate the optimal subband approximation of a given fullband system, when the quality of the approximation is measured by the power of the output error signal, assuming a white input signal. We have also provided a tight approximation error bound, for a given subband configuration, which applies in the case where the unknown system to be approximated is known to be FIR of a given order. Concerning system identification, have we provided a novel identification strategy which consists in identifying a “low quality” subband model and have used it to build a model for either subband or delay-free reconstruction. This identification strategy reduces the computational complexity of the identification process and yields significantly smaller asymptotic residual errors, when compared with the existing methods.

D.2 NONLINEAR FEEDBACK CONTROL OF A DUAL-STAGE ACTUATOR SYSTEM FOR REDUCED SETTLING TIME

Researchers: J. Zheng and M. Fu

This work has developed a nonlinear control method for dual-stage actuator systems to track a step command input fast and accurately. The method is innovative in that the primary actuator is allowed to have overshoot for a fast rise time and then the secondary actuator is controlled to reduce the overshoot caused by the primary actuator as the system output approaches the set-point. Experimental results demonstrate that this can further reduce the settling time significantly compared with conventional control.

D.3 SELECTING DIFFERENTIALLY EXPRESSED GENES USING MINIMUM PROBABILITY OF CLASSIFICATION ERROR

Researchers: P. Mahata and K. Mahata

Discovery of differentially expressed genes between normal and diseased patients is a central research problem in bioinformatics. It is specially important to find few genetic markers which can be explored for diagnostic purposes. The performance of a set of markers is often measured by the associated classification accuracy. This motivates our ranking of genes depending on the minimum probability of classification errors (MPE) for each gene. In this work, we have used Bayesian decision-making algorithm to compute MPE. A quantile-based probability density estimation technique has been used for generating probability density functions of genes.
The novelty of this method lies in finding previous methods for detecting periodicity. Many new genes which have non-sinusoidal expression data are discovered in datasets of yeast, human fibroblast cell-line period and shape of the periodic signals. This work, we have applied a novel non-parametric method based on a quadratic parametric method to find periodic genes from noisy datasets (like gene expression data) with very few periods and in the absence of any assumption on the shape of the signals and the number of samples.

D.4 PERIODICITY DETECTION IN SMALL SAMPLE GENE EXPRESSION DATA

Researchers: K. Mahata and P. Mahata

Analyses of any periodic biological phenomena like cell-cycle regulation, circadian rhythms, ovarian cycle, etc. demands finding periodicity in the data. Furthermore, cancer research is centred around the fact that the cancer is a result of uncontrolled cell proliferation. Thus studying periodic genes in normal and cancer cells is an intuitive way towards finding malignancies in the genes due to differences in shapes and periods of genes between a normal and a tumorous cell. In this work, we have applied a novel non-parametric method based on a quadratic optimisation formulation for detecting the period and shape of the periodic signals (gene expressions) in the gene expression datasets of yeast, human fibroblast cell-line and human cancer cell-line. We have found many new genes which have non-sinusoidal periodic shapes and which were missed by previous methods for detecting periodicity. The novelty of this method lies in finding periodic genes from noisy datasets (like gene expression data) with very few periods and in the absence of any assumption on the shape of the signals and the number of samples.

D.5 MAXIMISING CORRELATION FOR SUPERVISED CLASSIFICATION

Researchers: K. Mahata and P. Mahata

In this work, we have developed a novel feature selection and classification approach using the correlation maximisation paradigm. This approach is particularly interesting when the number of features is very large in comparison to the number of samples, as in the datasets arising in the bioinformatics applications. We give a simple, fast and reliable method for finding a separating hyperplane between two classes of samples in such data. Using this method, we have shown how to perform gene selection. Finally, we have validated the selected genes by using an independent classifier. We have illustrated our method by showing 100 genetic markers which act together in separating ovarian endometrioid tumors from other ovarian epithelial tumors. Notice that in the previous works, there was no single marker gene found for this purpose.

D.6 ROBUST IDENTIFICATION

D.6.1 Exact Identification of continuous-time systems from sampled data

Researchers: D. Marelli and M. Fu

Continuous-time system identification methods typically rely on the assumption that the continuous-time input and output signals are sampled “fast enough”. Therefore, the accuracy of the identification method depends on the sampling frequency. As a consequence, if the fast-sampling assumption is not very realistic, the results obtained are not very accurate. In this work, we have proposed a method in which we assume that the sampling of the input and output signals is done by using an arbitrary sampling device (i.e., assuming non ideal anti-aliasing filters and any arbitrary sampling frequency). Then, we use these discrete-time samples to tune the parameters of a continuous-time model of the system, taking into account the effects of the sampling devices. The advantage of the proposed method is that its accuracy becomes arbitrary good, as the number of discrete-time samples tends to infinite, for, in theory, any sampling frequency. In practice, however, the use of a very slow sampling frequency leads to numerical problems. Numerical simulations have shown that there exists a threshold frequency, such that if the sampling frequency is bigger than this threshold, the accuracy of the identification method is independent of the sampling frequency.

D.6.2 Approximate identification of continuous-time systems from sampled data

Researchers: J.I. Yuz (Universidad Técnica Federico Santa María, Chile) and G. C. Goodwin

Whilst most physical systems occur naturally in continuous time, it is usually necessary to deal with sampled data for identification purposes. In principle, one can derive an exact sampled data model for any given linear systems by integration. However, conversion to sampled data form implicitly involves folding. High frequency system characteristics back onto the lower frequency range. This means that there is an inherent loss of information. The sampling process is reversible provided one has detailed knowledge of the relationship between the low frequency and folded components so that they can be untangled from the sampled model. However, it is clear from the above argument that one has an inherent sensitivity to the assumptions that one makes about the folded components. The factors which contribute to the folded components include:

- The sampling rate.
- The nature of the input between samples (i.e., is it generated by a first order hold or not, or is it continuous time white noise or not).
- The nature of the sampling process (i.e., has an anti-aliasing filter been used and, if so, what are its frequency domain characteristics).
- The system relative degree (i.e., the high frequency roll-off characteristics of the system beyond the base band).
- High frequency poles and zeros that lie outside the base band interval.
We have shown that the above issues lead to nontrivial robustness issues. For example, we have shown that, in the identification of Continuous-time Auto-Regressive (CAR) models from sampled data, the resultant model depends critically on the assumptions one makes about the issues outlined above. We have also extended these ideas to general linear models. In particular, we have argued that one always needs to define a model depending on the assumptions and ensure that the analysis is restricted to that bandwidth. We have developed both time and frequency domain methods for ensuring insensitivity to high frequency folded artefacts – see Yuz and Goodwin (2007) in Chapters in Books.

**D.6.3 Robust identification of process models from plant data**

Researchers: G.C. Goodwin, J.-C. Agüero, J.S. Welsh, G.J. Adams, J.I. Yuz (Universidad Técnica Federico Santa María, Chile) and C.R. Rojas (Student)

A precursor to any advanced control solution is the step of obtaining an accurate model of the process. Suitable models can be obtained from phenomenological reasoning, analysis of plant data or a combination of both. A key goal is to achieve robust identification. By robust we mean that small errors in the hypotheses should lead to small errors in the estimated models. We have demonstrated that, in some circumstances, it is essential that special precautions be taken to ensure that robustness is preserved. We have studied several practical case studies which illustrate this circle of results – see Goodwin, Agüero, Welch, Adams, Yuz and Rojas (2007) in Plenary/Keynote Addresses.

**D.6.4 Frequency domain identification of MIMO state space models using the EM algorithm**

Researchers: J.-C. Agüero, J.I. Yuz (Universidad Técnica Federico Santa María, Chile) and G.C. Goodwin

In this project we have considered the problem of estimating a state-space model for Multiple-Input Multiple-Output systems. We have shown how the Expectation-Maximisation algorithm can be used in the frequency domain to obtain a Maximum Likelihood estimate for state-space models. This method can be applied to obtain robust estimates of the model focusing on a specific frequency band of the input/output data spectra. The proposed method can be used to identify systems excited with general input signals and it is able to deal with transients responses – see Agüero, Yuz and Goodwin (2007) in Conference Papers.

**D.6.5 A method for bias reduction in time domain least squares parameter estimation**

Researchers: J.S. Welsh, G.C. Goodwin and H. Garnier (Université Henri Poincaré, France)

This project is aimed at examining the bias that arises when applying least squares identification to continuous-time models of resonant systems. We have proposed a simple method to reduce the impact of this bias by pre-processing the data. The new method requires no knowledge of the noise colouring. We have examined a simple example and shown that the proposed method offers excellent results compared with traditional methods – see Welsh, Goodwin and Garnier (2007) in Conference Papers.

**D.7 CLOSED LOOP IDENTIFICATION**

**D.7.1 Choosing between open and closed loop experiments in linear system identification**

Researchers: J.-C. Agüero and G.C. Goodwin

In this project we have studied the optimality of open and closed loop experiments. We have shown that open loop experiments are optimal for a broad class of systems when the system input is constrained. In addition, we have shown that, for a general class of systems, when the output power is constrained, closed loop experiments are optimal. Both results use a strong notion of optimality and use expressions for estimation accuracy which are non-asymptotic in model order but asymptotic in data length – see Agüero and Goodwin (2007) in Journal Papers.

**D.8 ERROR IN VARIABLES**

**D.8.1 An improved bias-compensation approach for errors-in-variables model identification**

Researcher: K. Mahata

This work has provided a new algorithm for dynamics errors in variables modelling. We have shown that there exists a unique causal filter which must be used to filter the observed data in order to optimise the estimation accuracy. This filter is closely related to a particular type of Wiener filters.

**D.8.2 Identifiability of errors in variables dynamic systems**

Researchers: J.-C. Agüero and G.C. Goodwin

In this research project we have developed a single theorem which compactly summarises many of the known results in the EIV literature. The theorem also covers several cases which we believe to be novel. We have analyised single input single output systems using second order properties. We have also extended the results to a class of multivariable systems – see Agüero and Goodwin (2008) in Journal Papers to appear.
D.9 SYSTEM IDENTIFICATION USING QUANTISED DATA

Researchers: J.-C. Agüero, G.C. Goodwin and J.J. Yuz (Universidad Técnica Federico Santa María, Chile)

In this project we have considered the problem of identification of linear systems using quantised data. We have argued that, where possible, it is desirable to not utilise “naïvely” quantised data but instead it is preferable to choose the quantisation mechanism carefully. In particular, we have shown that using a generalised noise shaping coder improves the accuracy of the estimates. We have also examined the accuracy of estimates for both naïve and coded quantisers – see Agüero, Goodwin and Yuz (2007) in Conference Papers.

D.10 FREQUENCY-DOMAIN CONSTRUCTED REDUNDANT BASIS FOR DENOISING

Researchers: Jianyu Lin (University of Sydney) and G.C. Goodwin

In this project, redundant bases for denoising have been constructed in the frequency-domain. The advantage of the frequency-domain bases construction approach is that it provides more flexibility. As a result, the filterbank (basis) can be constructed to fit the features of the signal more closely, and the filter’s frequency response in the filterbank can be designed to be very close to the Gaussian curve so that the time-frequency localisation is close to optimal. Experimental results have shown that the new bases perform very well with signals that can be very difficult for denoising with conventional bases, such as conventional wavelets, wavelet packets, and wavelet frames etc – see Lin and Goodwin (2007) in Conference Papers.

D.11 OFDMA Uplink PAR Reduction via Tone Reservation

Researchers: Meng Wang, D.E. Quevedo, G.C. Goodwin and B.S. Krongold (University of Melbourne)

Orthogonal frequency division multiple access (OFDMA) has been widely recognised as a promising solution for broadband wireless networks. Unfortunately, in OFDMA uplink scenarios, high peak-to-average power ratios (PARs) degrade the power efficiency of the mobile users. This turns out to be one of the most critical problems when implementing OFDMA systems. In this research we have proposed an efficient PAR reduction scheme based upon tone reservation. We have shown, by simulation, that the PAR can be significantly reduced without incurring multiple-access interference and with a very small loss in bandwidth – see Wang, Quevedo, Goodwin and Krongold (2007) in Conference Papers.

Figure 36: The time-domain samples of an OFDM symbol in the complex plane
Typical sensors (CCD or CMOS) used in home digital camcorders have the potential for generating high definition (HD) video sequences. However, the data readout rate is typically a bottleneck which, invariably, forces significant quality deterioration in recorded video clips. In this project we have described a novel technology for achieving a better utilisation of sensor capability, resulting in HD quality video clips with essentially the same hardware. The technology is based on the use of a particular type of nonuniform sampling strategy. This strategy combines infrequent high spatial resolution frames with more frequent low resolution frames. This combination allows the data rate constraint to be achieved whilst retaining an HD quality output. Post processing via filter banks has been used to combine the high and low spatial resolution frames to produce the HD quality output – see Maor, Feuer and Goodwin (2007) in Journal Papers.
Program Goals: The Bayesian Learning Program comprises researchers from Engineering, Mathematics, Machine Learning and Statistics backgrounds, reflecting the strong interdisciplinary nature of the Centre. In 2007 the Program focused on the following four research themes: Parametric Bayesian Modelling, Bayesian Nonparametrics, Complex Systems and Bayesian Computation. Applications of this research included problems in genetics, environment and environmental health.

The Bayesian Learning Program is located in two nodes: one at QUT Brisbane, led by CI Mengersen, and the other at the University of Newcastle, led by Dr King and Professor John Rayner.

Major research activities in 2007 included development of theoretical, computational and applied Bayesian methods and models, publication of outputs in the form of journal articles and conference papers, conduct of an international workshop and professional short courses, participation in international conferences, hosting of international visitors, visits to international laboratories, supervision of postgraduate students and collaboration with other members of CDSC. These activities are detailed below.

Program Participants:

Program Leaders:  Professor Kerrie Mengersen (QUT node), Robert King, Professor John Rayner (UN node)

Academic Researchers:  Dr Darfiana Nur, Dr Julio Braslavsky (UoN), Dr Elizabeth Stojanovski, Dr Peter Howley

Research Associates:  Dr Ross McVinish, Dr Mark Griffin, Dr Jaime Peters, Dr Paula Lennon (QUT); Dr David Allingham, Dr Frank Tuyl (UoN)

Research Assistants:  Mr Sean Moynihan (QUT)

Continuing PhD students:  Trevor Moffet (UoN; submitted); Kate Lee, Darren Wraith, Christopher Oldmeadow (QUT)

Completed PhD students:  Dr Elizabeth Stojanovski, Dr Petra Graham, Dr Clair Alston, Dr Frank Tuyl

Honours students:  Joe Kelly (QUT)

Visiting PhD students:  Jennifer Tso (New Zealand, 6 months)

Project visitors:  Dr Cathal Walsh (Trinity College, Ireland), Professor Jean-Michel Marin (Paris, France), Professor Robert Wolpert (Duke University, USA)
E.1 PARAMETRIC BAYESIAN MODELLING

Project Leader: K. Mengersen

Project Members: J. Rayner, R. McVinish, M. Griffin, C. Alston, D. Wraith (Student), F. Tuyl (Student), J. Kelly (Honours student), J. Tso (visiting student, Auckland University), S. Moynihan (Research Assistant) and J. Peters (Research Associate)

E.1.1 Time series models

Honours student Joe Kelly developed a thesis on "Modelling dynamic covariance matrices with applications to portfolio optimisation" under the supervision of CI Mengersen. His research, which won him First Class Honours, focused on the methodology of two state of the art techniques used in modelling time varying covariance matrices, namely the deterministic dynamic conditional correlation multivariate generalised autoregressive conditional heteroscedasticity (DCC-MVGARCH) model and a stochastic volatility model. The two methods were implemented using quasi-maximum likelihood estimation and Bayesian inference via MCMC. The study examined the two methods under both simulation and practice by the use of a case study relevant to Australia’s economy. Mr Kelly has applied to undertake a PhD in Bayesian statistics at various international universities.

Dr McVinish has continued examining time series whose covariance functions are completely monotone, that is, they can be represented as the Laplace transform of a finite Borel measure. The paper studying the structural properties and estimation for this class of time series reported last year has been accepted in the Journal of Applied Probability. In a paper submitted this year, the problem of finding the covariance function having the completely monotone property which maximises the one step prediction error variance was studied. This problem was shown to be related to the problem of finding the extremising measures of a related moment space.

Dr Hamilton, Dr McVinish and Prof Mengersen have developed a time series model for the occurrences of Lyngbya blooms in Deception Bay. The occurrences of this noxious cyanobacteria were related to environmental variables through a probit regression and temporal dependence was incorporated using an autoregressive error structure. Variable selection was implemented using reversible jump MCMC. The model was able to produce well calibrated probability estimates of occurrence with a high level of accuracy.
E.1.2 Spatio-temporal mixture models
Dr Alston, Mr Wraith and Prof Mengersen continued to study Bayesian spatio-temporal mixture models, with a new focus on the formulation and impact of dynamic models expressed through data-based priors. These models were applied to air pollution particles and image data. Two different informative priors based on using only the past time point or all other time points to more clearly establish spatial and temporal patterns in such data, were compared with an independent prior using simulated and actual data. In addition, two models were considered in which these data-informed priors were placed at different hierarchical levels. This induces a different degree of smoothing and flexibility of characterisation of patterns.

E.1.3 Image classification
In collaboration with medical researchers in the Institute for Health and Biomedical Innovation, Dr Alston, Prof Mengersen and Mr Sean Moynihan continued research into Bayesian spatio-temporal mixture models for the problem of estimating volume of cement in hip replacements, based on (2-dimensional) CAT scan images and allowing for artifact. Research into the classification of brain images, using EEG and MRI, has continued, led in part by Dr Mark Griffin.

E.1.4 Meta-analysis
Research continued on Bayesian models for multivariate and repeated measures meta-analysis. Dr Cathal Walsh, from Trinity College in Ireland, visited the QUT node of the Centre Program in 2007 to continue investigation of the effect of model choice in meta-analysis.

Research into Bayesian models for meta-analysis in repeated measures study designs has been led by Dr Jaime Peters, in collaboration with CI Mengersen. The analysis of this type of design is complicated by the individual being the unit of measurement, not the observations taken on each individual, resulting in structural dependence of the data. There is currently little information available to inform the method of meta-analysis of repeated measures studies so that this dependence is appropriately accommodated and the findings are meaningful. In this activity, we examined possible approaches to this problem, including meta-analysis of data at specific time-points and the construction of regression slopes with time as the independent variable.

Dr Peters has also addressed the problem of combining results adjusted for different confounders. In collaboration with CI Mengersen and Dr Cathal Walsh, she proposed a Bayesian model for the partial adjustment of study estimates to account for potential confounding variables that were not adjusted for in the primary study. The reasons for selective reporting of adjusted estimates in observational epidemiological studies were also studied.
E.1.5 Bayesian priors
Centre student Frank Tuyl obtained his PhD degree with his thesis, “In Defence of Bayes (1763)”. Dr Tuyl was employed in the Centre during 2007 to write up his thesis work. Frank has submitted three papers on the long standing problem of interval estimation of the Binomial parameter.

E.2 BAYESIAN NONPARAMETRICS
Project Leader:  R. McVinish

This topic continued as a research theme in 2007. Two aspects were progressed: new methodology for goodness of fit testing, and the application of Bayesian nonparametrics to transfer function estimation.

E.2.1 Goodness of fit testing
Research progressed on Bayesian nonparametric goodness of fit testing, examining priors that permit faster evaluation of Bayesian conditional predictive p-values while retaining good asymptotic properties (McVinish, Rousseau, Mengersen). Researcher Ross McVinish will visit Professor Judith Rousseau in Paris in 2008 to further develop and apply this research. Dr McVinish and Prof Mengersen have further developed Bayesian goodness of fit methodology for the analysis of circular data. This has application to areas such as biology, geology and meteorology.

Prof John Rayner’s research in 2007 on goodness of fit testing has focused on the writing of a second edition of Rayner and Best (1989); this is joint work with Olivier Thas from Ghent University in Belgium and John Best, who is now a conjoint at Newcastle. The project, called ‘Smooth2’, was progressed by a visit from Olivier to CDSC Newcastle in January/February and a visit by Rayner to Dr Thas in Belgium in June/July. These collaborators are working towards a special issue of the Journal of Statistical Theory and Practice on Modern Goodness-of-Fit. The issue should appear late in 2008.

E.2.2 Transfer function estimation
Research by Drs McVinish and Braslavsky on Bayesian nonparametric transfer function estimation continues to be progressed. Initial work on developing priors for transfer functions which take into account known mathematical relationships has commenced. Specifically, attention has focused on a prior for minimum phase transfer functions based on the magnitude-phase relationship first derived by H.W. Bode. This work will be presented at the world meeting of ISBA in 2008.

Figure 43: Draft Bayesian network for relocation of cheetahs into fenced, protected areas.
E.3 COMPLEX MODELS

Project Leader: K. Mengersen
Project Members: R. King, P. Lennon (Research Associate), S. Johnson (Student) and C. Oldmeadow (Student)

E.3.1 Bayesian networks

Methodological and applied work with Bayesian networks continued with the completion of science and management models for the problem of identifying factors and solutions relating to the problem of lyngbya, a toxic cyanobacteria that infests our coastlines. A new project has been funded by Healthy Waterways, Queensland, to continue the maintenance and development of these models.

A new project on the development of Bayesian networks for rare and threatened species has been initiated. The first activity has been a visit by Centre researchers Mengersen and Johnson (Masters student) to Southern Africa (South Africa, Botswana) to collaborate with statisticians and cheetah conservation experts in order to develop a Bayesian network for survival of relocated cheetahs. This work will continue in 2008.

E.3.2 Genetics

Drs Darfiana Nur and David Allingham, visiting Centre research Prof Judith Rousseau (U. Dauphine, Paris, France) and Prof Mengersen, have continued researching the impact of priors on a Bayesian variable length Markov model for DNA sequence identification.

Research by PhD student Chris Oldmeadow and Prof Mengersen is continuing in collaboration with the Queensland Institute for Medical Research into Bayesian models for complex diseases. Focus has concentrated on genetic associations and the use of multiple data types.

Dr Paula Lennon is investigating the use of Bayesian logic models for the problem of analysis of DNA sequences. Collaborations on this topic have been established with Prof Katja Ickstadt and her colleagues in Germany.

E.3.3 Environment and health

Bayesian models for describing spatial and temporal epidemiological associations in environment and health contexts, and the interaction between environmental exposures and health, have been developed. Problems of this type have included hierarchical models for better description of health outcomes, interactive effects of temperature and ozone on mortality, environmental factors associated with the transmission of Ross River virus, and analysis of air pollution data.

Dr Howley’s research in this area has focused on Bayesian hierarchical modelling and its application to foster quality improvement activity in health care, through the creation of improved methods for analysis and reporting of clinical indicator data. This relates well with his research into ‘performance measures’, which extends beyond the health care field.

Mr Trevor Moffett was appointed as a Centre researcher in 2007 to write up his PhD thesis work on statistical methods for software and decision support for remote sensing analysis. This has focused on a prototype Bayesian method for modelling of foliage projective cover (FPC) by Landsat satellite Enhanced Thematic Plus (ETM+) remote sensing. The model allows the effective coupling of airborne and ground based calibration models as components of the main model for estimating FPC, as an areal proportion of each pixel, for the spectral imagery (ETM+ sensor) of a vegetated landscape.

Figure 44: Image of a Gold Coast scene developed from a disparate dry season land-based image at Injune, Qld.
E.4 COMPUTATIONAL METHODS

Project Leader: K. Mengersen

Project Members: R. King, D. Allingham and K. Lee (Student).

This research theme has continued to focus on two main activities in 2007.

E.4.1 New MCMC approaches

Profs Rousseau and Mengersen, and Drs Nur and McVinish have continued to investigate the use of Importance Sampling for faster MCMC analysis of complex models.

Research into the performance of Population Monte Carlo (PMC) in high dimensions has been progressed by Dr McVinish and PhD student Kate Lee. This scheme is a sampling technique that uses iterated importance sampling with the importance function depending on the previously generated samples. Optimality of the PMC algorithm was evaluated analytically and empirically. Its advantage over Markov Chain Monte Carlo (MCMC) methods is that the estimate is approximately unbiased (for an unnormalised target distribution) at each iteration. In practice, estimation of the asymptotic variance over iterations is very difficult and we approximate the general setup to a single step of PMC. This approximation is feasible due to an estimate that is approximately unbiased at each iteration. The asymptotic variance of the estimate is estimated for a given function of interest. When all covariance matrices are diagonal (all components are independent) the optimal proposal variance that gives the smallest asymptotic variance of estimate is computed analytically. The plot shows how the asymptotic variance of estimate (Var(H)) varies with different values for proposal variance. And one step of PMC approximates the general set up of PMC well.

Two cases of importance weight (target distribution/proposal distribution) have been considered: (i) unconditional importance weight where the proposal distribution is a marginal distribution over a sample from a previous iteration and (ii) conditional importance weights where the proposal distribution is a simple random walk centred at a sample from a previous iteration.

Future work will include study of the relation of optimising the algorithm and the dimension, correlation between components and a class of function of interest.
E.4.2 Approximate Bayesian computation

Approximate Bayesian computation (ABC) utilises random variable sampling to perform parameter estimation. It is applicable particularly to distributions for which no analytic likelihood function is available, as well as to models of arbitrary complexity, relying only on samples drawn from the function of interest with specified parameters.

ABC has been employed by researchers in the CDSC group for model selection, using generalised linear distributions for illustration, sensitivity analysis for hidden Markov model of DNA segmentation, and use of approximate Bayesian computation for DNA segmentation analysis.

Drs Allingham, Nur and King and Prof Mengersen have continued investigation of an ABC approach to Bayesian estimation of generalised distributions. Drs Allingham, Nur and King have also examined the use of ABC for DNA segmentation.

The algorithm has been applied to model selection for competing distributions, illustrating this with the normal, generalised lambda and g-and-k distributions. In this case, a current model flag is added as a parameter, and at each iteration one of these possible models is employed. The most appropriate model is selected, and, where more than one is appropriate (as in the case of normally-distributed data: this is a special case of the g-and-k distribution), the simplest.

As an expansion of the sensitivity analysis for DNA sequences lead by Darflana Nur, approximate Bayesian computation has also been applied to the underlying problem of segment identification. Although MCMC techniques can be applied to this problem for simple models, we have explored an approach which is applicable to arbitrarily complex models for which the likelihoods (required for MCMC) are not available or are too arduous to compute. The DNA sequence is viewed as a realisation of a Markov chain, in which different segments have different nucleotide transition matrices. We distinguish the segment types by using a set of moveable boundaries (rather than a hidden Markov model), turning the problem into a change-point problem. The issue here is to decide on a suitable summary statistic for the approximate Bayesian computational approach. A modified Kullback-Leibler divergence has been used which identifies the nucleotide transition matrix distributions, but is unable to identify the boundary locations. Some form of entropy-based measure may be suitable and is under investigation.

Work on these computational methods and statistical models have been applied Statistical methods continued to be applied to the BHP-Billiton project on Noise Reduction in Sferics. An MCMC approach to near-field (high-frequency) sferics detection was used to isolate sferics in the recorded time-series. A modified ABC approach was used for schedule assessment in the Integrated Mine Planning project, enabling estimation of the stability of non-optimised schedules as well as providing information about the relative frequencies of subschedules on short time-scales. This approach also paves the way for the incorporation of geological uncertainty in future work.

Figure 46: Parameter estimation of a quantile-based g-and-k distribution using ABC; posterior distributions and covariances for the four parameters
Program Goals: The object of the Program is to add to the battery of mathematical knowledge that allows us to better understand both continuous and discrete dynamic systems exhibiting complex behaviour. In addition, expertise of the CIs in modern analysis is exploited to aid the solution of problems driven by particular projects being undertaken by the Centre.

Overview of the situation in 2007: The first months of 2007 saw three members of the group (David Pask, Iain Raeburn, and Aidan Sims) move to the University of Wollongong with a consequent reduction in their engagement with the Centre. At much the same time the group was joined by George Willis as a potential CI. To further, ensure momentum was maintained it was also augmented by the appointment of three Visiting Professors (for periods ranging from one to four months).

The mathematics discipline at Newcastle is rebuilding and re-orientating with a greater emphasis on applicable mathematics. A Laureate Professor of Mathematics and a Professor of Applied Mathematics have already been appointed (both to take up their Chairs in early 2008) and further appointments are foreshadowed. As a result it is anticipated that the Mathematical Systems Theory group will be well placed to be able to both intensify and diversify its activities within the Centre.

Throughout 2007 research proceeded on a number of fronts:

**F.1 AUTOMORPHISMS OF CUNTZ ALGEBRAS**
Researchers: W. Szymanski., R. Conti, J. Kimberley, D. Robertson.

Cuntz algebras, and more generally graph algebras, are a very interesting class of C*-algebras whose structure and properties are closely related to certain combinatorial objects like directed graphs. They play an important role both in mathematics and theoretical physics. In this ongoing project, we study automorphisms of such algebras encoding internal symmetries related to certain symbolic dynamical systems. The techniques involved are a mixture of analysis and combinatorics, and are supported by massive computer calculations being carried out by Jason Kimberley.

**F.2 BEYOND THE SPECTRUM**
Researchers: G. Willis, F. Ghahramani (Winnipeg), C. Read (Leeds) and J. Kimberley

Various transforms that are important in applications of mathematics, such as the Fourier and Laplace transforms and diagonalisation of matrices, convert a complicated multiplication in an algebra to a pointwise multiplication of functions. This technique relies on the existence of a space, sometimes called the maximal ideal space or the spectrum of the algebra, on which the functions are supported. However such a space does not always exist, for example, nilpotent matrices and Volterra integral operators cannot be represented as functions on a space, and in this situation the algebra is called radical.

The aim of this project is to develop methods for analysing radical algebras.

1. In 2007 Willis, with F. Ghahramani (Winnipeg) & C. Read (Leeds), worked jointly on a paper "Closed ideal structure and cohomological properties of certain radical Banach algebras" (43 pages). This paper shows that certain algebras, which at first sight seem very exotic, have a rich structure that may be described in great detail.

2. Work was begun on another paper with C. Read that introduces the concept of "just integral domain" and aims to develop a classification scheme for radical algebras based on this concept. The algebras studied in this work will populate one of the classes in this scheme. Willis reported on this work in a plenary talk on "Radical Banach Algebras" at the conference Banach Algebras ’07 in Quebec in July.
3. Experimental calculations concerning the structure of another class of radical convolution algebras are underway. The fundamental concept in the analysis of algebras is that of an ‘ideal’ (a subspace of the algebra closed under multiplication by all elements of the algebra). Fourier and Laplace transforms, for example, represent the algebra as functions on the set of maximal ideals of the relevant algebra. Discrete convolution algebras over the positive rationals are not well understood in terms of their ideal structure, but we have reduced the problem of finding ideals to an infinite sequence of linear programming problems. J. Kimberley has been implementing the first few terms in this sequence and some promising candidates for ideals have been identified. It will still need to be proved analytically that these are new ideals.

F.3 C*-ALGEBRAS AND NONCOMMUTATIVE GEOMETRY

Researchers: W. Szymanski, J.H. Hong (Busan), P.F. Baum (Penn State), P. Bertozzini (Bangkok), P. Chakraborty (Chennai) and R. Conti

C*-algebra is a collection of Hilbert space operators closed in norm and under the natural algebraic operations including involution. Such structures are used for example in quantum physics to model state and phase spaces of systems with infinitely many degrees of freedom. This project aims at developing mathematical machinery that would allow application of methods similar to classical differential geometry in the context of spaces on which variables do not commute, such as those arising in quantum mechanics. Our main focus has been on extending the cut-and-paste techniques of classical topology to this new environment and their applications to spectral analysis. Symmetry of the underlying structure is often crucial in such considerations and this is captured by an action of a quantised group on a noncommutative space.

F.4 GRAPH ALGEBRAS

Researchers: I. Raeburn, D. Pask, W. Szymanski

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

In 2007, Raeburn and Damian Marelli (who works primarily in the Signal Processing program in CDSC) used actions of groups on graph algebras to provide examples of actions which are proper in Rieffel’s sense, but which are not saturated.

F.5 NONLINEAR ANALYSIS AND FIXED-POINT THEORY

Researchers: B. Sims, C. Lennard (USA), Gang Li (China), S. Dhompongsa (Thailand), K. Goebel (Poland), E. Llorens Fuster (Spain), A. Kirk (USA), H. Hudzyk (Poland), Francisco Eduardo Castillo Santos (Student), I. Searston (Student), M. Smith (Student)

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

A principal goal in this research programme is to further our understanding of nonexpansive and related types of mappings, with an emphasis on identifying readily applied, yet widely applicable, criteria that ensure the existence of fixed points for such maps together with effective algorithms by which they can be approximated. Special emphasis is given to the more difficult cases, where the underlying space lacks the nice geometric structure exhibited by, for example, a Hilbert space, or where there is no natural linear structure present.

During 2007, our investigations focussed on the following.

F.5.1 Analysis in the absence of linearity

In situations where there is no intrinsic linear structure present (for example; certain instances of image reconstruction and aspects of pattern recognition and cognitive modelling) one must rely on non-algebraic (geometric) properties of the space to carry the analysis.

Recently it has been observed that certain geodesic (or Menger convex) metric spaces, in particular the so called CAT(0) spaces, provide a very general setting in which a rich analysis seems possible. Professor Art Kirk has made an important start toward developing a fixed point theory for nonexpansive type mappings and multifunctions in this setting. We have been working to extend this and to establish projection algorithms for solving ‘convex’ feasibility problems.

F.5.2 Fixed points in the absence of weak compactness

In mid 2006 Pie-Kee Lin obtained a seminal result which answered (unexpectedly) in the negative a widely investigated conjecture first raised by Sims nearly three decades ago. Lin showed under an equivalent dual renorming, initially considered by Lennard and Dowling, that the nonreflexive space X = l1 enjoyed the fixed point property for nonexpansive maps (fpp); that is, for all nonempty closed bounded convex subsets C of X all nonexpansive mappings T:C:C have a fixed point. Previously it had been conjectured this would only happen if X were reflexive. Chris Lennard, Castillo Santos and Sims have been investigating, already with encouraging success, what
special features of this particular norm ensure it has the fpp, in order to establish the fpp for a class of renormings for $l_1$ and for other spaces.

**F.5.3 Semigroups of mappings**

The existence of (common) fixed points, asymptotic behaviour and ergodic theory for (semigroups of) nonlinear mappings have proved important in many areas, including the study of evolving systems, control theory and optimisation. Led by Gang Li, we have obtained very general demiclosedness principles, on not necessarily convex sets, and results of the three types for (commutative semigroups of) both certain Lipschitzian; nonexpansive, and non-Lipschitzian; asymptotically nonexpansive, mappings on (Banach) special metric spaces.

**F.5.4 Ultraproduct methods**

Banach space ultra-products, and more recently ultra-products of metric spaces, represent a common meeting ground between standard and non-standard analysis, and have become powerful tools in both linear and nonlinear analysis. They have proved central to the fixed point theory of nonexpansive type mappings in the absence of strong geometric properties, such as normal structure, and are particularly suited to the analysis of attainment problems. By lifting the problem to an ultra-power approximate solutions become exact solutions (for example; an approximate eigenvalue of an operator corresponds to an eigenvalue of the lifted operator).

Refinements of these techniques and their application to a wide variety of problems is one of our major focuses. A research monograph on this topic by the project leader and one of his students, Mark Smith, is undergoing final proof reading prior to publication by Springer-Verlag in 2008.

**F.6 THE STRUCTURE OF TOTALLY DISCONNECTED GROUPS**

Researchers: G. Willis, G. Schlichting (Germany) and U. Baumgartner

Other Support: Australian Research Council Discovery Grant

An important concept in this area is that of “flatness” of automorphism groups (it corresponds to simultaneous diagonalibility of matrices). U. Baumgartner and G. Willis had conjectured a geometric criterion for flatness that was inspired by some work of Schlichting 25 years ago. We were able to establish this criterion under an additional hypothesis on the group and work will continue to remove this extra condition.

**F.7 WAVELET BASES**

Researchers: I. Raeburn, K. Mahata, T. Yeend, N. Larsen (Oslo), J. Packer (Colorado), L. Baggett (Colorado) K. Merrill (Colorado)

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

In one approach to the construction of wavelets, a central role is played by a pair of operators satisfying an algebraic relation which is very similar to those arising in graph algebras. In 2004, Larsen and Raeburn exploited the geometrical information implicit in this relation to recognise the multiresolution analysis used in the construction of wavelets as a direct limit of Hilbert spaces.

Raeburn devoted a considerable part of his effort in 2007 to applying these ideas to more general structures called generalised multi-resolution analyses. He, Baggett, Merrill and Packer (U. of Colorado, Boulder, USA), and Larsen (Oslo, Norway) have used these methods to solve a problem about the existence of generalised multiresolution analyses with given multiplicity function, and submitted a paper on the subject late in 2007.
PUBLICATIONS * Denotes international author

CHAPTERS IN BOOKS


PLENARY AND KEYNOTE ADDRESSES


JOURNAL PAPERS


JOURNAL PAPERS
ACCEPTED FOR PUBLICATION:


T. Perez and P. Steinmann, “Modelling and performance of an active heave compensator for offshore operations”, IFAC Conference on Control Applications in Marine Systems (CAMS), Bol, Croatia, September.
TECHNICAL REPORTS TO INDUSTRY:

BHP-Billiton Innovation

BHPB/IMP/07/01
C.R. Rojas, G.C. Goodwin and M.M. Seron,

BHPB/IMP/07/02
C.R. Rojas, G.C. Goodwin and M.M. Seron,

BHPB/IMP/07/03

BHPB/IMP/07/04
M. Zhang, G.C. Goodwin and M.M. Seron,

BHPB/IMP/07/05

BHPB/OB/OG/07/01
K. Lau, D. Allingham and J.H. Braslavsky,

BHPB/OB/OG/07/02
K. Lau, F. De Ridder, D. Allingham and J.H. Braslavsky,

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K. Lau, D. Allingham and J.H. Braslavsky,

BHPB/OB/OG/07/04
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BHPB/OB/OG/07/05
K. Lau, J.H. Braslavsky and G.C. Goodwin,

BHPB/OB/OG/07/06

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Mat/NGMT/07/10

Mat/NGMT/07/11

Mat/NGMT/07/12

Robotiker-Tecnalia

Robotiker/07/01

Robotiker/07/02

Halcyon International

Halcyon/07/01

Halcyon/07/02
### PERFORMANCE INDICATORS REPORT

#### P.1 RESEARCH TRAINING

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#### P.2 RESEARCH TRAINING AND PROFESSIONAL EDUCATION

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INTERNATIONAL, NATIONAL AND REGIONAL LINKS AND NETWORKS

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P.3 INTERNATIONAL, NATIONAL AND REGIONAL LINKS AND NETWORKS

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</tr>
<tr>
<td>Visits to Overseas Labs</td>
<td>17</td>
<td>20</td>
<td>14</td>
<td>12</td>
<td>20</td>
<td>Allingham – Ghent University, Belgium; Hong Kong Polytechnic University; Fu – National Lab for Scientific Computation, Brazil; Zhejiang University, China; Chinese Academy of Sciences; South China University of Technology; Goodwin – Imperial College, UK; Lund University, Sweden; Université Laval, Canada; Washington University, St Louis, USA; Mengersen – NCEAS, Santa Barbara, USA; Dauphine University, Paris, France; South African Statistical Society, South Africa and Botswana; Moheimani – Hong Kong University of Science &amp; Technology, Chinese University of Hong Kong; IBM Research Labs, Zurich, Switzerland; EPFL Lausanne, Switzerland; Rayner – Ghent University, Belgium (2); Welsh – Nancy University, France;</td>
<td>10</td>
<td>50</td>
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</table>
P.4 END-USER LINKS

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>Postgraduate Students involved in industrial projects (New students only)</td>
<td>7</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td></td>
<td>Cristian Rojas – BHP-Billiton Boris Godoy – BHP-Billiton</td>
<td>10</td>
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<tr>
<td>Visits by Centre Researchers to Industry</td>
<td>7</td>
<td>12</td>
<td>7</td>
<td>23</td>
<td>22</td>
<td>Adams – Matrikon (7); CSR (4); BHP-Billiton (1) Allingham, Braslavsky, Lau – BHP-Billiton (9) Goodwin – BHP-Billiton (4) Perez – BHP-Billiton (1)</td>
<td>5</td>
<td>25</td>
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P.5 ORGANISATIONAL SUPPORT

<table>
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<tr>
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</thead>
<tbody>
<tr>
<td>Annual cash contributions from collaborating organisations</td>
<td>$400K</td>
<td>$475K</td>
<td>$450K</td>
<td>$648K</td>
<td>$633K</td>
<td>BHP-Billiton Innovation: $100,000 Matrikon: $50,000 University of Newcastle: $300,000 NSW Department of State and Regional Development: $111,000 Queensland University of Technology: $21,600 (to QUT node) Industrial Affiliates: $50,000</td>
<td>$450K</td>
<td>$2250K</td>
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<tr>
<td>In-kind contributions from collaborating organisations</td>
<td>$1746K</td>
<td>$2818K</td>
<td>$2818K</td>
<td>$2846K</td>
<td>$3910K</td>
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<td>$1.5M</td>
<td>$7.5M</td>
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P.6 GOVERNANCE

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<tbody>
<tr>
<td>Advisory Board</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>Advisory Board Meeting held on 27 April 2007</td>
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P.7 NATIONAL BENEFIT

<table>
<thead>
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<tbody>
<tr>
<td>Student Placements in other organisations</td>
<td>5</td>
<td>7</td>
<td>6</td>
<td>1</td>
<td>3</td>
<td></td>
<td>Robert Denham – Principal Statistician, Queensland Department of Natural Resources and Water, Queensland, Australia Michael Quinlan – Artificial Intelligence Laboratory, College of Natural Sciences, University of Texas, Austin, USA Frank Tyul – HunterHealth, Australia</td>
<td>2</td>
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<tr>
<td>Case Studies of Benefits</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>CDSC jointly with Engineers Australia (NCACI and Process Control Society), Rio Tinto and CSSIP, financially sponsored a study: “Achieving the Benefits of Improved Control in Australian Process and Manufacturing Industries”.</td>
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<tr>
<td>Industry Technical Reports</td>
<td>9</td>
<td>23</td>
<td>38</td>
<td>31</td>
<td>31</td>
<td>See page 67</td>
<td>5</td>
<td>25</td>
</tr>
<tr>
<td>Account Name</td>
<td>Central Accounts (Combined)</td>
<td>Control System Design</td>
<td>Control &amp; Optimisation</td>
<td>Parameter Estimation (Connell Wagner)</td>
<td>Mathematical Systems Theory (UoN)</td>
<td>Bayesian Learning</td>
<td>Bayesian Learning (QUT)</td>
<td>TOTAL</td>
</tr>
<tr>
<td>-------------</td>
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<td>------------------------</td>
<td>---------------------------------------</td>
<td>---------------------------------</td>
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<tr>
<td>Account Number</td>
<td>P510-701</td>
<td>P513-1438, 1499</td>
<td>P513-1439</td>
<td>P513-1440</td>
<td>P513-1441</td>
<td>P513-1442</td>
<td>P513-1454</td>
<td>P513-1475</td>
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<td>2007 ANNUAL REPORT</td>
<td>71</td>
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### INCOME AND EXPENDITURE STATEMENT FOR THE YEAR ENDED 31ST DECEMBER 2007

#### Income

- **Salaries (Academic):**
  - 2006-07: 30,148
  - 2007-08: 256,924
  - 2008-09: 137,822
  - 2009-10: 300,780
  - 2010-11: 170,460

#### Non-Salary Expenditure

- **Consumables:**
  - 2006-07: 61,605
  - 2007-08: 2,265
  - 2008-09: 736
  - 2009-10: 18,653
  - 2010-11: 7,066

#### Total Income

<table>
<thead>
<tr>
<th>Year</th>
<th>2006-07</th>
<th>2007-08</th>
<th>2008-09</th>
<th>2009-10</th>
<th>2010-11</th>
<th>TOTAL</th>
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<tbody>
<tr>
<td></td>
<td>2006 b/f</td>
<td></td>
<td></td>
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<tr>
<td>2007</td>
<td>366,313</td>
<td>938</td>
<td>352,702</td>
<td>308,186</td>
<td>164,616</td>
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<tr>
<td>2008</td>
<td>1,700</td>
<td>2,106</td>
<td>300,780</td>
<td>170,460</td>
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<tr>
<td>2009</td>
<td>1,700</td>
<td>2,106</td>
<td>300,780</td>
<td>170,460</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td>1,700</td>
<td>2,106</td>
<td>300,780</td>
<td>170,460</td>
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</tr>
</tbody>
</table>

#### Salary Expenditure

- **Salaries (Academic):**
  - 2006-07: 30,148
  - 2007-08: 256,924
  - 2008-09: 137,822
  - 2009-10: 300,780
  - 2010-11: 170,460

#### Non-Salary Expenditure

- **Consumables:**
  - 2006-07: 61,605
  - 2007-08: 2,265
  - 2008-09: 736
  - 2009-10: 18,653
  - 2010-11: 7,066

#### Total Salary & Related Costs

<table>
<thead>
<tr>
<th>Year</th>
<th>2006-07</th>
<th>2007-08</th>
<th>2008-09</th>
<th>2009-10</th>
<th>2010-11</th>
<th>TOTAL</th>
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<tbody>
<tr>
<td>2006</td>
<td>80,186</td>
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<tr>
<td>2007</td>
<td>256,924</td>
<td>938</td>
<td>352,702</td>
<td>308,186</td>
<td>164,616</td>
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<tr>
<td>2008</td>
<td>1,700</td>
<td>2,106</td>
<td>300,780</td>
<td>170,460</td>
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<tr>
<td>2009</td>
<td>1,700</td>
<td>2,106</td>
<td>300,780</td>
<td>170,460</td>
<td></td>
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</tr>
<tr>
<td>2010</td>
<td>1,700</td>
<td>2,106</td>
<td>300,780</td>
<td>170,460</td>
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<td></td>
</tr>
</tbody>
</table>

#### Total Salaries & Related Costs

- **Total Salaries & Related Costs:**
  - 2006-07: 80,186
  - 2007-08: 256,924
  - 2008-09: 1,700
  - 2009-10: 1,700
  - 2010-11: 1,700

#### Total Expenditure

<table>
<thead>
<tr>
<th>Year</th>
<th>2006-07</th>
<th>2007-08</th>
<th>2008-09</th>
<th>2009-10</th>
<th>2010-11</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>537,286</td>
<td>20,964</td>
<td>193,483</td>
<td>239,238</td>
<td>52,167</td>
<td>111,396</td>
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<td>2007</td>
<td>248,376</td>
<td>21,600</td>
<td>111,396</td>
<td>1,703,742</td>
<td>1,362,936</td>
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NOTES