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Abstract

This report contains a short overview over the ongoing research and teaching activities of the PhD-students of the Department of Automatic Control, Lund University, in 2002.

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Contents

Automotive and Engine Control Applications

Johan Bengtsson

Start of project	1999-04-01
Plan	PhD 2004
Supervisor	Rolf Johansson, Karl-Erik Årzén
Course Credits	48
Publications:	1 Licentiate Thesis, 4 Conference Articles.

Research Problem and State of the Art

Adaptive Cruise Control and Driver Models

The project aims to design a driver model including a model of a human driver's behavior in traffic. The model should describe a human driver's longitudinal control of his vehicle related to a front vehicle. Typical situations that the model needs to handle are: the driver approaching another car; following the front car; a car cutting in from another lane; the front car braking hard. The model should represent the driver's behavior equally well in highway traffic and in urban traffic.

A model like this can be used as an instrument to improve driver comfort and the road safety as well as driving-support devices. In USA there was 2.2 million rear-end collisions in 1990 and nearly half of these collisions were due to drivers following their front car too closely.

Although scientists have studied similar problem since the 1950s with considerable new attention in the 1990s, this problem still has no satisfactory solution. Today there exist both descriptive and cognitive models, but the cognitive models still have a long way to go. The models which exist today come from people occupied with traffic flow and from traffic simulations. Previously, such models have only included a very simple model of the driver, but nowadays there are attempts to have a good model of the single driver. Many of the car manufacturers are today working on driver-support systems that handle the longitudinal control of the vehicle. The first European system has just started to sell. In Japan the first system entered the market in 1995, but this system has poor performance and some people count the first European system as the first real ACC system (Adaptive Cruise Controller). Today Daimler-Benz sells an ACC system which works in highway situations and every car manufacturer is also familiar with ACC systems. In fall 1998 a Master Thesis at Volvo resulted in a stop-and-go con-

troller for adaptive cruise controller. All these systems represent an elaboration of the standard cruise control.

GIHR

This work focus on Homogeneous Charge Compression Ignition (HCCI). It is a joint project with Volvo Technical development, Volvo Truck, Scania, DAMEK at Royal Institute of Technology, Department of Automatic Control at Lund Institute of Technology, Division of Combustion Engine at Lund Institute of Technology, Division of Combustion Physics at Lund Institute of Technology, and Department of Thermo and Fluid Dynamics at Chalmers. Today most of the worlds engines used in cars or trucks are either a spark engine or a Diesel engine. They both have their advantages and disadvantages. The HCCI can be describe as a hybrid of Spark Ignition (SI) engine and Diesel engine. A premixed air-fuel mixture is used just like in a SI engine but the charge is not ignited by a spark. Instead the charge is ignited by the compression heat as is the case in a Diesel engine.

Goals

Adaptive Cruise Control and Driver Models

The goal is to achieve a model that describe a human driver's longitudinal behavior of his car related to the car in front. The model should feel comfortable for the driver and represent the behavior in the standard situations.

GIHR

The goal is to increase knowledge, develop methods, calculation tools and prototypes for use of HCCI.

Design and run one or more HCCI engine with following features:

- Load up to 20 bar IMAP
- 40% conversion efficiency
- NOx emissions less than 10ppm
- Smoke emissions less than ppm
- Combustion efficiency greater than 98%
- Emissions of HC and CO on a level which can be taken care by a oxidation Catalyst
- Control of load and rpm

Research Approach

Adaptive Cruise Control and Driver Models

Many of the models which exist today are static. Therefore, the first approach is to check the presence of dynamics using system identification. The first method that I will use to get a dynamic model is a sub space method. It is also necessary

to do literature research on driver behavior and human physiological function, which are significant of the behavior, such as the judgment of distance. In order to get a model of the human driver, it is necessary to collect relevant data an a lot of test cases have to be specified.

GIHR

First different control variables will be studied. There are 4 different control variables which are used in HCCI. In this project we will use some of them.

- Variable valve timing, VVT. Advantages: capable to handle transient operation and variation in speed and load. Disadvantages: add cost and complexity to engine.
- Variable compression ratio, VCR. Advantages: capable to handle transient operation and variation in speed and load. Disadvantages: add cost and complexity to engine.
- Thermal control, Exhaust Gas Recirculation (EGR). Advantages: simple and need no major engine modification. Disadvantages: slow.
- Ignition-enhancing additives, 2 fuels with different octane ratings. Disadvantages: need to refill to 2 fuels. Ideally, the amount of the secondary fuel being consumed would be minimal. and the tank could be refueled only at maintenance intervals.

It is also necessary to study which signal shall be used in the feedback.

Results

- Proposed a dynamic model of the human driver

Milestones

- Autumn 2001 Licentiate Thesis

External Contacts

Adaptive Cruise Control and Driver Models

The project is done in cooperation with Volvo Technological Development (Div. Driving Support Systems), which supply the test car and their knowledge to the project.

GIHR

The project is done in cooperation with
Volvo Technical Development
Volvo Truck
Scania
DAMEK at Royal Institute of Technology
Division of Combustion Engine at Lund Institute of Technology

Division of Combustion Physics at Lund Institute of Technology
Department of Thermo and Fluid Dynamics at Chalmers

Course Work

Now I have 48 points

Service to the Department

Teaching

I have been teaching assistant in the course

Course	
AK(E)	Fall 1999
AK(M)	Spring 2000
AK(E)	Fall 2000
AK(E)	Fall 2001
AK(FD)	Fall 2001
System Identification	Spring 2002

Master Thesis supervisor

Bourmpos, M. (2001): "Vision based robotic grasping tracking of a moving object." Technical Report Masters thesis ISRN LUTFD2/TFRT–5675–SE. Department of Automatic Control, Lund Institute of Technology, Sweden.

Conde Bento, L. and D. Mendonca (2001): "Computer vision and kinematic sensing in robotics." Technical Report Masters thesis ISRN LUTFD2/TFRT–5670–SE. Department of Automatic Control, Lund Institute of Technology, Sweden.

Luis de Mena, J. (2002): "Virtual environment for development of visual servoing control algorithms." Technical Report Masters thesis ISRN LUTFD2/TFRT–5686–SE. Department of Automatic Control, Lund Institute of Technology, Lund, Sweden.

Correll, N. (2002): "6-dof visual servoing using the lie group of affine transformation." Technical Report Masters thesis ISRN LUTFD2/TFRT–5690–SE. Department of Automatic Control, Lund Institute of Technology, Sweden.

Olsson, T. (2001): "Vision guided force control in robotics." Technical Report Masters thesis ISRN LUTFD2/TFRT–5676–SE. Department of Automatic Control, Lund Institute of Technology, Sweden.

Publications

Bengtsson, J. (2001): "Adaptive cruise control and driver modeling." Technical Report Licentiate thesis ISRN LUTFD2/TFRT–3227–SE. Department of Automatic Control, Lund Institute of Technology, Sweden.

Bengtsson, J., A. Ahlstrand, K. Nilsson, A. Robertsson, M. Olsson, A. Heyden, and R. Johansson (2000): “A robot playing scrabble using visual feedback.” In *6th Int. IFAC Symposium on Robot Control (SYROCO 2000)*. Vienna, Austria.

Bengtsson, J., M. Haage, and R. Johansson (2002): “Variable time delays in visual servoing and task execution control.” In *2nd IFAC Conference on Mechatronic Systems*. Berkeley.

Bengtsson, J., R. Johansson, and A. Sjögren (2001): “Modeling of drivers longitudinal behavior.” In *2001 IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM'01)*. Como,Italy.

Olsson, T., J. Bengtsson, R. Johansson, and H. Malm (2002): “Force control and visual servoing using planar surface identification.” In *IEEE Int. Conference on Robotics and Automation*, pp. 4211–4216.

Integrated Control and Scheduling

Anton Cervin

Start of Project	1998-05-01	**Plan**	PhD 2003
Supervisors	Karl-Erik Årzén, Per Hagander	**Course Credits**	80
Publications:	1 licentiate thesis, 2 journal articles, 10 conference papers		

Research Problem and State of the Art

In the design of real-time control systems, there has been separation between the design of controllers and their actual implementation as tasks in computers. The first thing to realize is that the performance of digital controllers is subject to the constraints of the computer system. The second thing to realize is that control tasks have special properties and therefore require special scheduling techniques. While a number of sophisticated scheduling techniques exist, such as value-based or flexible scheduling, they have not been specifically developed with control systems in mind. Also, very few papers have considered a continuous exchange of information between controllers and the scheduler, in order to improve the schedulability and control performance. It remains to develop scheduling techniques, control analysis, and co-design methods for such systems.

Goals

- Develop analysis and co-design methods for multitasking real-time control systems that take the specific timing attributes of control tasks—period, delay, and jitter—into account.
- Develop Matlab-based tools for analysis and simulation of real-time control systems. The analysis tool can evaluate the impact of delay and jitter on control performance. The simulator allows the execution of control tasks to tbe simulated in conjunction with the continuous process dynamics.
- Investigate feedback scheduling, i.e. scheduling and control techniques that achieves higher utilization of the computing resources and better control performance while allowing a few deadlines to be missed.
- Develop a scheduling model for real-time control tasks that allows controllers to be treated as components with predictable control and real-time behavior.

- Implement the new scheduling algorithm in the STORK kernel and perform some feedback scheduling experiments.

Research Approach

We intend to combine ideas from scheduling theory and control theory to develop techniques that give better control performance and higher resource utilization. The project is not limited to any specific process models and controllers. As a first step a linear quadratic formulation of the control problem has been considered. We will also look at the scheduling of more computing-intensive controllers, such as model predictive controllers. The project partners at the Department of Computer Science have been investigating interactive worst-case execution time analysis, and there current efforts are focused at feedback scheduling of real-time garbage collection.

The tools used are mainly MATLAB and SIMULINK for both design and evaluation of controllers and schedulers. The real-time kernel at the department (STORK) is also being doctored for the implementation and experimental evaluation of the techniques.

Results

- An in-depth state-of-the-art survey about integrated control and scheduling has been written [Årzén *et al.*, 1999, Årzén *et al.*, 2000].
- Scheduling of the two main parts of a control algorithm (*Calculate Output* and *Update State*) has been investigated [Cervin, 1999].
- A MATLAB/SIMULINK-based simulator for real-time control systems has been developed [Eker and Cervin, 1999]. A reference manual has been written [Cervin, 2000a]. A new, event-based version called TRUETIME has also been developed [Henriksson *et al.*, 2002c, Cervin *et al.*, 2003]
- Feedback scheduling of hybrid control tasks has been investigated [Cervin and Eker, 2000]. The approach is further developed in [Cervin *et al.*, 2002a], where optimization-based feedback scheduling of linear controllers is treated. Feedback scheduling has also been applied to event-based PID controllers, and most recently, to MPC controllers [Henriksson *et al.*, 2002a, Henriksson *et al.*, 2002b].
- A tool called JITTERBUG for evaluation of a quadratic performance index for linear controllers has been developed [Lincoln and Cervin, 2002, Cervin *et al.*, 2002b, Cervin *et al.*, 2003]. It makes it possible to investigate the effects of period, delay, jitter, and missed deadlines on control performance.
- A new scheduling model for control tasks, called the Control Server Model, has been developed and is currently being implemented.

Milestones

December 2002	Submit conference paper on the Control Server Model.
Spring 2003	PhD thesis finished.

External Contacts

During May–July 1998 I visited Lui Sha at the Software Engineering Institute in Pittsburgh, PA. Since then, Lui Sha has become a professor at the University of Illinois at Urbana Champagne. During September 2001 I visited Edward Lee and the Ptolemy group at University of California at Berkeley.

Universities

- The Department of Computer Science, Lund Institute of Technology
- The Software Engineering Institute, Carnegie Mellon University, Pittsburgh, PA, USA
- The Department of Computer Science, University of Illinois at Urbana-Champaign, IL, USA
- The Department of Electrical Engineering and Computer Science, University of California at Berkeley, CA, USA

Industries

- Sigma Exallon AB, Malmö. Contact person: Jan Johansson Enejder
- DDA Consulting, Malmö. Contact person: Ola Dahl

Course Work

I have 80 course credits.

Service to the Department

Teaching

I have been a teaching assistant in the following courses:

Course	Taught
Computer-Controlled Systems	Spring 2002, Spring 2001, Spring 2000
Real-Time Systems	Fall 2001, Fall 2000, Fall 1999, Fall 1998
Automatic Control, Basic Course	Fall 2002, Spring 1999

Master Thesis Supervision

I have been a co-supervisor in the following master thesis projects:

Gagner, J. and R. Bondesson (2000): "Adaptive real-time control of nonlinear throttle unit." Master thesis ISRN LUTFD2/TFRT--5638--SE. Department of Automatic Control, Lund Institute of Technology, Lund, Sweden.

Hörjel, A. (2001): "Bluetooth in control." Master thesis ISRN LUTFD2/TFRT--5659--SE. Department of Automatic Control, Lund Institute of Technology, Lund, Sweden.

Hörjel's thesis has also led to a conference paper: [Eker *et al.*, 2001].

Publications

Årzén, K.-E., B. Bernhardsson, J. Eker, A. Cervin, K. Nilsson, P. Persson, and L. Sha (1999): "Integrated control and scheduling." Technical Report ISRN LUTFD2/TFRT–7586–SE. Department of Automatic Control, Lund Institute of Technology, Sweden.

Årzén, K.-E., A. Cervin, J. Eker, and L. Sha (2000): "An introduction to control and scheduling co-design." In *Proceedings of the 39th IEEE Conference on Decision and Control*. Sydney, Australia.

Cervin, A. (1999): "Improved scheduling of control tasks." In *Proceedings of the 11th Euromicro Conference on Real-Time Systems*, pp. 4–10. York, UK.

Cervin, A. (2000a): "The real-time control systems simulator–Reference manual." Technical Report ISRN LUTFD2/TFRT–7592–SE. Department of Automatic Control, Lund Institute of Technology, Sweden.

Cervin, A. (2000b): "Towards the integration of control and real-time scheduling design." Technical Report Licentiate thesis ISRN LUTFD2/TFRT–3226–SE. Department of Automatic Control, Lund Institute of Technology, Sweden.

Cervin, A. and J. Eker (2000): "Feedback scheduling of contol tasks." In *Proceedings of the 39th IEEE Conference on Decision and Control*. Sydney, Australia.

Cervin, A., J. Eker, B. Bernhardsson, and K.-E. Årzén (2002a): "Feedback-feedforward scheduling of control tasks." *Real-Time Systems*, **23:1**.

Cervin, A., D. Henriksson, B. Lincoln, and K.-E. Årzén (2002b): "Jitterbug and TrueTime: Analysis tools for real-time control systems." In *Proceedings of the 2nd Workshop on Real-Time Tools*. Copenhagen, Denmark.

Cervin, A., D. Henriksson, B. Lincoln, J. Eker, and K.-E. Årzén (2003): "Analysis and simulation of controller timing." *IEEE Control Systems Magazine*. To appear.

Eker, J. and A. Cervin (1999): "A Matlab toolbox for real-time and control systems co-design." In *Proceedings of the 6th International Conference on Real-Time Computing Systems and Applications*, pp. 320–327. Hong Kong, P.R. China.

Eker, J., A. Cervin, and A. Hörjel (2001): "Distributed wireless control using Bluetooth." In *Proceedings of the IFAC Conference on New Technologies for Computer Control*. Hong Kong, P.R. China.

Henriksson, D., A. Cervin, J. Åkesson, and K.-E. Årzén (2002a): "Feedback scheduling of model predictive controllers." In *Proceedings of the 8th IEEE Real-Time and Embedded Technology and Applications Symposium*. San Jose, CA.

Henriksson, D., A. Cervin, J. Åkesson, and K.-E. Årzén (2002b): "On dynamic real-time scheduling of model predictive controllers." In *Proceedings of the 41st IEEE Conference on Decision and Control*. Las Vegas, Nevada.

Henriksson, D., A. Cervin, and K.-E. Årzén (2002c): "Truetime: Simulation of control loops under shared computer resources." In *Proceedings of the 15th IFAC World Congress on Automatic Control*. Barcelona, Spain.

Lincoln, B. and A. Cervin (2002): "Jitterbug: A tool for analysis of real-time control performance." In *Proceedings of the 41st IEEE Conference on Decision and Control*.

Persson, P., A. Cervin, and J. Eker (2000): "Execution-time properties of a hybrid controller." Technical Report ISRN LUTFD2/TFRT–7591–SE. Department of Automatic Control, Lund Institute of Technology, Sweden.

Automotive Control Applications

Magnus Gäfvert

Start of project	1996-07-25
Plan	PhD 2002
Supervisor	Björn Wittenmark, Karl-Erik Årzén
Course Credits	»86
Publications:	5 Journal Articles, 8 Conference Articles.

Research Problem and State of the Art

DICOSMOS

This work focuses on distributed control in safety critical real-time systems with special application to the automotive industry. It is a joint project with The Mechatronics Department at the Royal Institute of Technology, and the Computer Engineering Department at Chalmers Technical University, within the NUTEK project DICOSMOS.

A relevant problem within this area is to provide a design methodology for these systems such that

- communication effects like random delays and lost samples are handled properly
- specifications are guaranteed to be met at all working conditions
- safe operation can be ensured during failures
- communication channels are utilised efficiently

Distributed safety critical real-time systems are of great importance in the automotive industry. Volvo Technological Development is participating in the project by providing a case study. The case study is to design an active stability-control system for an articulated truck-trailer combination vehicle, by using distributed braking and possibly rear-wheel steering. Part of this work is the synthesis of a dynamic model for the truck-semitrailer combination vehicle, and the study of yaw control algorithms.

Similar systems are manufactured for passenger cars. Much research effort is spent on this area at many academic and industrial institutions. The contribution of this project is the focus on methodology, and the integration of communications and control. The actuator combination of individual braking and rear wheel steering is also new, to our knowledge. New yaw control algorithms based on tyre-road friction models are studied.

FAMIMO

A parallell research track is the application of linear feedback control and extremum control on a Gasoline Direct Injection (GDI) Engine, within the EU project FAMIMO. The GDI engine is a benchmark problem provided by Siemens Automotive in Toulouse, France, to evaluate different control synthesis methodologies. The main feature of the GDI engine is that it can be operated in an ultra-lean combustion mode, which may result in better fuel economy and less exhaust emissions. The engine requires very careful control to operate properly. The GDI engine is a complex system to control, including process variations, nonlinearities and hybrid mode switches. The control objectives are to ensure engine operation while maintaining driver comfort and optimizing economy. Standard engine control systems are based on open loop approaches with lookup-tables. New sensor technology and the introduction of fairly powerful processing capabilities within the engine compartment enables the use of more elaborate control algorithms, including feedback and online optimization.

Friction

Previous research efforts involve investigations on dynamics friction models, in particular the celebrated LuGre model. Relations with other friction models have been established, and some interesting properties has been analyzed and stated. The application of the model in friction compensation has been explored.

Goals

DICOSMOS

The case study is expected to result in methodologies for designing safety critical real-time integrated communications and control systems. New results on vehicle dynamics control and modelling may also result from the work.

FAMIMO

The goal is to show that simple standard control algorithms can perform well in the context of engine control, and that they constitute competitive alternatives to the commonly used open-loop approaches based on lookup-tables. A new “silent” extremum controller has been presented, that may be explored further.

Friction

The main goal is to find a connection with my current research areas, so that I can use some of the friction results in my thesis. A possible approach may be to explore the applicability of the LuGre model on road-tyre surface contact modelling.

Research Approach

DICOSMOS

The complete system will include a computer architecture including ECUs and buses, in combination with an algorithmic architecture represented by the con-

troller partitioning. Combinations of centralized and distributed computer architectures, with centralized and distributed controller partitionings are discussed and evaluated with respect to performance, safety, cost and dependability. Based on this work a final system architecture will be chosen, and analyzed further. Current system architectures has been reviewed to provide background for this research.

For the development of the control algorithms, a first step has been to construct new dynamic models of the truck-trailer combination. One model includes yaw dynamics, a sophisticated description of tyre-road contacts using "Slip-Circle" models, and simple dynamic models of the braking system pneumatics. The model has been implemented in Simulink. It is validated by comparisons with a multi-body model constructed in the modelling environment COMPAMM. A more complete model that includes pitch and roll dynamics and load force distribution was also been derived and implemented in Simulink. The model is used to validate the active stability-control algorithms. Simulation results indicate good agreement with validation experiments on a real tractor-semitrailer vehicle. The model is delivered to Volvo Truck Corporation.

FAMIMO

Our approach is to introduce feedback wherever possible to handle robustness constraints, and to use extremum control as a means for online optimization with respect to fuel economy. Since the engine is a fairly large and complex system, a bottom-up approach has been adopted, resulting in a cascade structure of the control system. Simple linear controllers (PI etc) has been used extensively to keep the level of complexity low. Feedback linearisation techniques have been used to make way for the use of simple linear controllers. Elaborate state-machine based algorithms for mode switches has been developed.

Results

DICOSMOS

A review of current system architectures are presented in [Sanfridsson *et al.*, 2000]. New vehicle models are presented in [Gäfvert *et al.*, 2000b, Gäfvert and Lindgärde, 2001, Gäfvert and Lindgärde, 2003]. System architecture discussions and analysis is presented in [Claesson *et al.*, 2000]. Studies on active stability control of tractor-semitrailer vehicles are reported in [Gäfvert, 2001b]. Analysis of the effect of data-errors in digital controller implementations are discussed in [Askerdal *et al.*, 2002]. A method to render a controller implementation more robust to transient data-errors is presented in [Gäfvert and Askerdal, 2003].

FAMIMO

Results on the GDI engine control is presented in the conference submissions [Gäfvert *et al.*, 2000a, Gäfvert *et al.*, 2000], in the book chapter [Gäfvert and Årzén, 2002], and in the full paper [Gäfvert *et al.*, 2003]. The work has been well received within the automotive research community.

Friction

Investigation of model properties, and relations to other friction models are presented in [Gäfvert, 1997, Olsson *et al.*, 1998]. Application of the LuGre model

in friction compensation is described in [Panteley *et al.*, 1997, Panteley *et al.*, 1998, Gäfvert, 1999, Gäfvert *et al.*, 1999].

Milestones

Fall 2002 Finish writing!

External Contacts

The DICOSMOS project has Volvo Technological Development as industrial partner. During two years I spent approximately 1 week per month at VTD in Göteborg. I also spent time at the other participating universities: the Royal Institute of Technology, Chalmers Technical University.

Siemens Automotive is participating in the FAMIMO project. I have presented results to Siemens Automotive at a visits in Toulouse, France, and to researchers from Ford Motor Company in Dearborn, USA.

Universities

Chalmers Technical University

Royal Institute of Technology

Industries

Volvo Technological Development

Siemens Automotive

Course Work

I have fulfilled the course requirements for the Ph.D. with »86 points.

Service to the Department

Teaching

I have been assisting teacher in the following courses:

Course	Last Taught
The Art of Engineering	Fall 2002
International Project Course	Fall 2002
The Art of Engineering	Fall 2001
International Project Course	Fall 2001
System Identification	Spring 2001
Real-time Systems	Fall 2000
System Identification	Spring 2000
Real-time Systems	Fall 1999
Computer Controlled Systems	Spring 1999
Real-time Systems	Fall 1998
BEST Summer School	Summer 1998
Computer Controlled Systems	Spring 1998
Real-time Systems	Fall 1997
Basic Course (M)	Spring 1997
Basic Course (FED)	Fall 1996

Others

Participating in the development of the interactive learning tools for control *ICTools* [Zackrisson, 1997, Johansson *et al.*, 1998].

Participated in the reorganization of the laboratory exercises in Computer Controlled Systems to Linux with Matlab/Simulink with real-time enhancements.

Publications

Andersson, L., M. Gäfvert, S. Hedlund, and C. Johnsson (1998): "Praktikfall i reglerteknik – råspritbränneriet i Nöbbelöv," (Industrial case studies in control – the crude alcohol distillery in Nöbbelöv). Technical Report ISRN LUTFD2/TFRT–7573–SE. Department of Automatic Control, Lund Institute of Technology, Sweden.

Askerdal, Ö., M. Gäfvert, M. Hiller, and N. Suri (2002): "A control theory approach for analyzing the effects of data errors in safety-critical control systems." In *Proceedings of the Pacific Rim International Symposium on Dependable Computing*.

Claesson, V., M. Gäfvert, and M. Sanfridsson (2000): "Proposal for a distributed computer control system in heavy-duty trucks." Technical Report (00-16). Computer Engineering, Chalmers University of Technology, Sweden, Computer Engineering, Chalmers University of Technology, Sweden.

Gäfvert, M. (1996): "Comparison of two friction models." Technical Report Masters thesis ISRN LUTFD2/TFRT–5561–SE. Department of Automatic Control, Lund Institute of Technology, Sweden.

Gäfvert, M. (1997): "Comparisons of two dynamic friction models." In *Proc. Sixth IEEE Conference on Control Applications (CCA)*. Hartford, Connecticut.

Gäfvert, M. (1998): “Modelling the Furuta pendulum.” Technical Report ISRN LUTFD2/TFRT–7574–SE. Department of Automatic Control, Lund Institute of Technology, Sweden.

Gäfvert, M. (1999): “Dynamic model based friction compensation on the Furuta pendulum.” In *Proceedings 1999 IEEE Int. Conf. Control Applications and the Symp. Computer Aided Control Systems Design (CCA'99&CACSD'99)*. Kohala Coast, Hawaii.

Gäfvert, M. (2001a): “Modelling of the ETH helicopter laboratory process.” Technical Report ISRN LUTFD2/TFRT–7596–SE. Department of Automatic Control, Lund Institute of Technology, Sweden.

Gäfvert, M. (2001b): “Studies on Yaw-control of heavy-duty trucks using unilateral braking.” Technical Report ISRN LUTFD2/TFRT–7598–SE. Department of Automatic Control, Lund Institute of Technology, Sweden.

Gäfvert, M. and K.-E. Årzén (2002): *Control of Gasoline Direct Injection Engines using Torque Feedback*. Lund, Sweden. .

Gäfvert, M., K.-E. Årzén, and L. M. Pedersen (2000): “Simple linear feedback and extremum seeking control of GDI engines.” In *Proceedings of Seoul 2000 FISITA World Automotive Congress*. Seoul, Korea.

Gäfvert, M., K.-E. Årzén, L. M. Pedersen, and B. Bernhardsson (2003): “Control of gasoline direct injection engines using torque feedback: A simulation study.” *Control Engineering Practice*. Accepted for publication.

Gäfvert, M. and Ö. Askerdal (2003): “On the effect of transient data-errors in controller implementations.” In *American Control Conference*. Submitted.

Gäfvert, M. and O. Lindgärde (2001): “A 9-DOF tractor-semitrailer dynamic handling model for advanced chassis control studies.” Technical Report ISRN LUTFD2/TFRT–7597–SE. Department of Automatic Control, Lund Institute of Technology, Sweden.

Gäfvert, M. and O. Lindgärde (2003): “A 9-DOF tractor-semitrailer dynamic handling model foradvanced chassis control studies.” *Vehicle System Dynamics*. Submitted.

Gäfvert, M., L. M. Pedersen, K.-E. Årzén, and B. Bernhardsson (2000a): “Simple feedback control and mode switching strategies for GDI engines.” In *SAE 2000 World Congress*. Detroit, Michigan, USA. SAE Technical Paper 2000-01-0263.

Gäfvert, M., M. Sanfridsson, and V. Claesson (2000b): “Truck model for yaw and roll dynamics control.” Technical Report ISRN LUTFD2/TFRT–7588–SE. Department of Automatic Control, Lund Institute of Technology, Sweden.

Gäfvert, M., J. Svensson, and K. J. Åström (1999): “Friction and friction compensation in the Furuta pendulum.” In *Proc. 5th European Control Conference (ECC'99)*. Karlsruhe, Germany.

Johansson, M., K. J. Åström, and M. Gäfvert (1998): “Interactive tools for education in automatic control.” *IEEE Control Systems*, **18:3**, pp. 33–40.

Olsson, H., K. J. Åström, C. C. de Wit, M. Gäfvert, and P. Lischinsky (1998): “Friction models and friction compensation.” *European Journal of Control*.

Panteley, E., R. Ortega, and M. Gäfvert (1997): “An adaptive friction compensator for global tracking in robot manipulators.” In *Proc. SYROCO ’97, 5th IFAC Symposium on Robot Control*. Nantes, France.

Panteley, E., R. Ortega, and M. Gäfvert (1998): “An adaptive friction compensator for global tracking in robot manipulators.” *Systems & Control Letters*, **33:5**, pp. 307–313.

Sanfridsson, M., V. Claesson, and M. Gäfvert (2000): “Investigation and requirements of a computer control system in a heavy-duty truck.” Technical Report KTH/MMK/R–00/5–SE. Mechatronics Lab, Royal Institut, Stockholm, Sweden.

Zackrisson, M. (1997): “Matteprogram får eleverna att förstå tekniken,” (Math software makes students understand technology). Ny Teknik, Nr. 48.

Control of Open Plate Reactors

Staffan Haugwitz

Start of project	2002-08-01	**Plan**	PhD 2007
Supervisor	Per Hagander and Anders Rantzer	**Course Credits**	24
Publications:			

Research Problem and State of the Art

The aim of this project is to develop a control system for a plate reactor. The control system should e.g. be able to handle start-up and shutdown modes as well as achieving and maintaining optimal operating conditions for the process.

A plate reactor is a modified plate heat exchanger, where one side is a reactor, with reacting chemicals and the other side is a water flow. Depending on the reaction, there is a need for the water flow to cool or heat the reactor, i.e. whether the reaction is exothermic or endothermic. By combining a reactor and a plate heat exchanger, the resulting plate reactor has a substantially higher heat transfer capability (just to mention one of the advantages) compared to a normal batch reactor process.

When the reactions are exothermic and fast, the reactans are often disolved into low concentration solutions to ensure that the temperature in the batch reactor does not rise above a dangerous level (the state of the art today). By using a plate reactor, solutions of higher concentrations can be used, thus increasing the productivity and safety at a lower cost.

Goals

The objectives of the control system are the following:

- Utilize reactor maximally in a safe way
- Reaction is to be completed within the reactor
- Reactants are to be in the right proportions
- Should be able to work with concentrated solutions
- Avoid side reactions
- Achieve and maintain desired operating conditions
- Fast and safe start-up/shut-down
- Emergency shut-down procedure
- Robustness towards disturbances in the process

Research Approach

The process studied will be the plate reactor during the entire project. The control system will be developed in several steps. The first step is to learn and understand the plate reactor and the chemical processes. A rough model will be used to design a first simple controller to handle the temperature control. There will be itensified collaboration with the other partners of the project to gather information and experimental data about the process. The data might then be used in system identification of the process.

The modelling tool of the project will be Modelica, where the models will be derived by PDE's in parallel with models built by components from the ThermoFluid Library.

Results

A rough model based on PDE's has been developed and basic temperature control of a normal heat exchanger has been investigated.

Milestones

December 2002	A pre-study of the control system should be complete
April 2003	Project progress meeting, where experiments with a control system for the first basic reactions should be presented

External Contacts

The project is run by Alfa Laval AB in Lund, in collaboration with Alfa Laval Europe and other universities and institutes. There are regular project progress meetings in order to formally exchange results along the way. Apart from these meetings, there are additional meetings directly between partners of the project.

Universities and Institutes

Laboratoire de Ge'nie Chimique (LGC) in Toulouse

Industries

Alfa Laval AB

Course Work

I have 19 extra credits from the Master's program. During the fall I am studying Linear Systems so at the end of the year I will have 24 credits.

Service to the Department

Teaching

I have been teaching assistant in the following courses

Course	Last Taught
AK(M)	Fall 2002
AK(FDI)	Fall 2002

Other duties:

I am responsible for the department's contacts with the book shop KFS.

Optimal Control of Hybrid Systems

Sven Hedlund

Start of project	1997-09-01	**Plan**	PhD 2003
Supervisor	A. Rantzer, K.-E. Årzén	**Course Credits**	66
Publications:	1 licentiate thesis, 3 conference papers, 1 journal paper.		

Research Problem and State of the Art

Hybrid systems are systems that involve interaction between discrete and continuous dynamics. Modeling and simulation of a system often require a combination of mathematical models from a variety of engineering disciplines. The structure of such submodels can be very different, some can be discrete and some continuous.

Practical control systems typically involve switching between several different modes, depending on the range of operation. The fundamental problem with these systems is their complex mixture of discrete and continuous variables; even if the dynamics in each mode is simple and well understood, automatic mode switching can give rise to unexpected phenomena. The current lack of analysis methods compels control designers to rely on simulations.

Goal

The goal of this project is to develop analysis and synthesis methods for hybrid systems.

The first stage of the research lead to a discretization method of a hybrid version of the Hamilton-Jacobi-Bellman inequality. The method turns the optimal control problem into a linear program, resulting in a lower bound of the value function.

Current research is focused on finding an *upper* bound of the value function, posing a dual problem. The aim is to find a dual formulation of the "hybrid HJB inequality" and a discretization scheme that preserves bound properties without being too conservative.

Whatever direction the research takes, the resulting methods should be tested on several examples — school examples to examine the performance on well known problems, as well as problems in industry to verify practicability.

Research Approach

The current approach is to approximate and reformulate partly continuous problems into linear programming.

Results

Joint work with Mikael Johansson during the years of 1998 and 1999 resulted in a MATLAB toolbox for analysis and synthesis of piecewise linear systems [Hedlund and Johansson, 1999b, Hedlund and Johansson, 1999a]. The toolbox is mainly based on LMI computations.

Later work focused on the discretization of a hybrid version of the Hamilton-Jacobi-Bellman inequality. The method, called convex dynamic programming (CDP), gives a lower bound on the optimal value function [Hedlund and Rantzer, 1999b, Hedlund and Rantzer, 2002].

A toolbox that implements the CDP method is documented in [Hedlund, 1999].

Current work focuses on the dual problem of the CDP method, to parameterize the problem in the control signal rahter than the value function, and to prove tightness of the bounds. The first steps of this work were presented in [Hedlund and Rantzer, 2000].

Milestones

Fall 1999	Lic Tech Thesis
Summer 2000	Compile a journal article
Summer 2001	75%
Spring 2003	PhD Thesis

Course Work

I have acquired 66 credit points so far.

Service to the Department

Teaching

I have been teaching assistant in the following courses

Course	Last Taught
Adaptive Control	Fall 2001
Automatic Control, Basic Course	Fall 2000
Real Time Systems	Fall 1999
Nonlinear Control and Servo Systems	Spring 1999
BEST Summer School	Summer 1998
Computer-Controlled Systems	Spring 1998

Publications

Andersson, L., M. Gäfvert, S. Hedlund, and C. Johnsson (1998): "Praktikfall i reglerteknik – råspritbränneriet i nöbbelöv," (Industrial case studies in

control – the crude alcohol distillery in Nöbbelöv). Technical Report ISRN LUTFD2/TFRT–7573–SE. Department of Automatic Control, Lund Institute of Technology, Sweden.

Hedlund, S. (1999): "Computational methods for hybrid systems." Technical Report Licentiate thesis ISRN LUTFD2/TFRT–3225–SE. Department of Automatic Control, Lund Institute of Technology, Sweden.

Hedlund, S. and M. Johansson (1999a): "PWLTool, a Matlab toolbox for piecewise linear system." Technical Report ISRN LUTFD2/TFRT–7582–SE. Department of Automatic Control, Lund Institute of Technology, Sweden.

Hedlund, S. and M. Johansson (1999b): "A toolbox for computational analysis of piecewise linear systems." In *Proceedings of European Control Conference*. Karlsruhe, Germany.

Hedlund, S. and A. Rantzer (1999a): "CDP tool, a matlab tool for optimal control of hybrid systems.".

Hedlund, S. and A. Rantzer (1999b): "Optimal control of hybrid systems." In *Proceedings 38th IEEE Conference on Decision and Control(CDC'99)*. Phoenix, Arizona.

Hedlund, S. and A. Rantzer (2000): "Hybrid control laws from convex dynamic programming." In *Proceedings of IEEE Conference of Decision and Control*.

Hedlund, S. and A. Rantzer (2002): "Convex dynamic programming for hybrid systems." *IEEE Transactions on Automatic Control*, **47:9**, pp. 1536–1540.

Flexible Embedded Control Systems

Dan Henriksson

Start of project	2000-12-01	**Plan**	PhD 2005
Supervisors	Karl-Erik Årzén Björn Wittenmark	**Course Credits**	43
Publications:	1 Journal Article, 3 Conference Articles.		

Research Problem and State of the Art

Embedded real-time control systems have traditionally been relatively static systems. However, technology advances (Internet, mobile device technology) and market demands (use of COTS components) are rapidly changing the situation. This evolution towards more dynamic systems will make flexibility a key design attribute for future systems. Development of flexible scheduling techniques, control analysis, and co-design methods for these systems are therefore desirable.

The use of control-based approaches in analysis and design of embedded systems is currently receiving increased interest in the real-time systems community. However, much remains to be done to develop flexible and reliable scheduling and control design techniques for embedded real-time control systems in these dynamic environments.

Goals

- Investigate scheduling of compute-intensive control algorithms, in particular model predictive control, where an interesting trade-off exists between the time spent on optimization and the quality of the obtained control signals.

- Investigate the possibility of combining flexible control algorithms (e.g. hybrid control, model predictive control, event-based sampling) with flexible scheduling algorithms (e.g. feedback scheduling, scheduling of imprecise computations, etc).

Research Approach

The tools used are mainly MATLAB and SIMULINK for both design and evaluation of controllers and schedulers. The SIMULINK-based real-time control systems simulator developed at the department is used as a research tool.

Results

- TRUETIME, an event-based MATLAB/SIMULINK-based simulator for real-time control systems has been developed [Henriksson *et al.*, 2002c, Cervin *et al.*, 2002].

- A journal article [Cervin *et al.*, 2003] on analysis and simulation of control loop timing has been accepted for publication in Control Systems Magazine.

- A preliminary study of dynamic scheduling of model predictive controllers has been performed[Henriksson *et al.*, 2002a, Henriksson *et al.*, 2002b]. Scheduling decisions are made based on information from the optimization algorithm.

Milestones

Fall 2003 Licentiate Thesis
Fall 2005 PhD

Course Work

As of August, 2001 I have 43 course points. At the end of this year I intend to have 55 credits.

Service to the Department

Teaching

I have been teaching assistant in the following courses

Course	Last Taught
Automatic Control, Basic Course	Spring 2001
Real-Time Systems	Fall 2001
Computer-Controlled Systems	Spring 2002

I have also been responsible for a laboratory exercise in the course Nonlinear Control and Servo Systems. During the fall of 2002, I will be teaching assistant in Real-Time Systems.

Administrative Duties

- I have been responsible for the documentation of written exams since December 2000.

Publications

Cervin, A., D. Henriksson, B. Lincoln, and K.-E. Årzén (2002): "Jitterbug and TrueTime: Analysis tools for real-time control systems." In *Proceedings of the 2nd Workshop on Real-Time Tools*. Copenhagen, Denmark.

Cervin, A., D. Henriksson, B. Lincoln, J. Eker, and K.-E. Årzén (2003): "Analysis and simulation of controller timing." *IEEE Control Systems Magazine*. To appear.

Henriksson, D., A. Cervin, J. Åkesson, and K.-E. Årzén (2002a): "Feedback scheduling of model predictive controllers." In *Proceedings of the 8th IEEE Real-Time and Embedded Technology and Applications Symposium*. San Jose, CA.

Henriksson, D., A. Cervin, J. Åkesson, and K.-E. Årzén (2002b): "On dynamic real-time scheduling of model predictive controllers." In *Proceedings of the 41st IEEE Conference on Decision and Control*. Las Vegas, Nevada.

Henriksson, D., A. Cervin, and K.-E. Årzén (2002c): "Truetime: Simulation of control loops under shared computer resources." In *Proceedings of the 15th IFAC World Congress on Automatic Control*. Barcelona, Spain.

Henriksson, D., R. Johansson, and A. Robertsson (2001): "Observer-based impedance control in robotics." In *Proceedings of the 5th IFAC Symposium "Nonlinear Control Systems" (NOLCOS'01)*, pp. 365–370. St. Petersburg, Russia.

Loop and Quality Assessment

Performance monitoring of λ tuned controllers

Ari Ingimundarson

Start of project	1999-February	**Plan**	PhD 2003
Supervisor	Tore Hägglund	**Course Credits**	78

The previous project on "Dead-Time Compensation Controllers for the Process Industry" has been finished and the project "Loop and Quality Assessment" has been started. Publications which resulted from the project were [Ingimundarson and Hägglund, 2000b, Ingimundarson and Hägglund, 2000a, Ingimundarson and Hägglund, 2001, Ingimundarson and Hägglund, 2002].

Research Problem and State of the Art

The objectives of this project are to develop tools to automatically analyze the performance of a controller or groups of controllers in a plant. The methodology has been tested in a paper mill.

Goals

In this new project we plan to make a study of how performance monitoring methods a paper mill can be related to the tuning of the controllers. The project will give us answers to the following important questions:

- How good/bad is the control quality in a typical Swedish paper mill?
- How is it compared to the expectations implicitly associated with the tuning of the loop?
- Is it possible to make an automatic loop assessment, so that the quality can be checked routinely?
- How much do we gain by making these loop assessments and control improvements?

The main gain from relating methods to the tuning is that need for historical data should be reduced.

Research Approach

A new method based on estimating the synthetic gradient of a qudratic cost function has been suggested. Many theoretical questions remain unanswered

and the hope is these will be cleared up. The new method allows the frequency content of the disturbances affecting the control loop to be analyzed with regard to controller parameters.

An method for performance monitoring has been presented which relates the monitoring algorithm with the tuning of the loop so that alarms are sounded when performance is poorer than expected from the tuning.

Results

The methods have been tested in a Paper mill with promising results. The methods have performed as expected and indicated when appropriate reduction in performance. One conference article has been published [Ingimundarson, 2002]

Other research activitites

In cooperation with Stefan Solyom a new design method for PID controllers was developed. See [Solynom and Ingimundarson, 2002].

Milestones

Fall 2002 Finish writing PhD thesis.

External Contacts

Industries

ABB Automation

Modo Paper Husum

Hylte Bruk

Course Work

- 2002-10-13 I have 78 credits

Service to the Department

Teaching

I have been teaching assistant in the following courses

Course	Last Taught
Automatic Process Control (K)	Spring 1999
Automatic Control Basic Course (FED)	Fall 1999
Computer Controlled Systems	Spring 2000
Real-Time Systems	Fall 2000
System Identification	Spring 2001
Real-Time Systems	Fall 2001
Automatic Control Basic Course (FID)	Fall 2002

Publications

Ingimundarson, A. (2002): "Performance monitoring of pi controllers using a synthetic gradient of a quadratic cost function." In *IFAC World Congress*. Barcelona, Spain.

Ingimundarson, A. and T. Hägglund (2000a): "Closed-loop identification of first-order plus dead-time model with method of moments." In *ADCHEM 2000, IFAC International Symposium on Advanced Control of Chemical Processes*. Pisa, Italy.

Ingimundarson, A. and T. Hägglund (2000b): "Robust automatic tuning of an industrial PI controller for dead-time systems." In *IFAC Workshop on Digital Control – Past, present, and future of PID Control*. Terrassa, Spain.

Ingimundarson, A. and T. Hägglund (2001): "Robust tuning procedures of dead-time conpensating controllers." *Control Engineering Practice*, **9**, pp. 1195–1208.

Ingimundarson, A. and T. Hägglund (2002): "Performance comparison between pid and dead-time compensating controllers." *Journal of Process Control*, **12**, pp. 887–895.

Solynom, S. and A. Ingimundarson (2002): "A synthesis method for robust pid controllers for a class of uncertainties." *Accepted for publication in Asian Journal of Control*.

Control and Networks

Bo Lincoln

Start of project	1999-02-01	**Plan**	PhD 2003
Supervisors	Anders Rantzer and Björn Wittenmark	**Course Credits**	≈ 75
Publications:	8 conference articles 2 Journal articles (1 more in preparation)		

Research Problem and State of the Art

The research project started in the field of networked control system (NCS), especially involving wireless networks. In the course of time, two main tracks have been explored:

1. Analysis of delay and jitter effects in control systems. These problems are always introduced when using networks in control loops.
2. Development of optimal control methods for switched systems and other nonlinear extensions of linear systems. Things like "attention" scheduling for distributed control systems can be addressed in this context.

Goals

- Develop suboptimal Dynamic Programming methods with guaranteed error bounds for the kind of problems described above.
- Study stability properties of networked control systems in presence of delays.
- Develop compensation techniques for delays.

Results

- Optimal control of systems with stochastic time-delays in control loops has been investigated, a work started and largely investigated by Johan Nilsson at the department. With Bo Berhardsson I have published [Lincoln and Bernhardsson, 2000b].
- Time delay stability in linear systems has been proven using small gain theorem, leading to a Bode diagram condition. Published in [Lincoln, 2002b].
- Development of a compensation technique for systems with delays using loop-shaping methods. Published in [Lincoln, 2002a].

- A toolbox in Matlab called JITTERBUG has been developed to easily calculate LQ-costs and spectral densities for mixed continuous/discrete-time systems with random delays. The conference papers [Lincoln and Cervin, 2002] and [Cervin *et al.*, 2002] as well as the journal article [Cervin *et al.*, 2003] describe the toolbox.
- Control scheduling (in hybrid/switched systems) is optimized using dynamic programming. An algorithm finding the optimal solution is published in [Lincoln and Bernhardsson, 2000a] and [Lincoln and Bernhardsson, 2002].
- The above dynamic programming has been relaxed to find non-optimal solutions provably close to the optimal. This is published in [Lincoln and Rantzer, 2001] and [Lincoln and Rantzer, 2002].

Milestones

Summer 2000	Literature study of network routing and analysis.
April 2001	Material enough for a lic. thesis, 50% done.
Spring 2002	Continued research.
Christmas 2002	Material enough for thesis (80% finished).

Course Work

I now have 75 credits. At the end of this year I intend to have 80 credits.

Service to the Department

Teaching

I was in the working group to form the new Digital Control course in 2002. Specifically, I developed the new DVD player lab in cooperation with AudioDev AB in Malmö.

I have been teaching assistant in the following courses

Course	Last Taught
AK(F)	Fall 2002
Digital control systems (new course)	Spring 2002
Nonlinear systems	Spring 2001
Real-time systems (project)	Fall 2000
AK(E)	Fall 2001
AK(M)	Spring 1999

Administrative Duties

- Supervising Johan Kaunitz in his master's thesis work aimed at decrease computational complexity in a DVD controller.
- Supervised Athir Gattami in an Ultrasound positioning system project to be used in student projects.

Publications

Cervin, A., D. Henriksson, B. Lincoln, and K.-E. Årzén (2002): "Jitterbug and TrueTime: Analysis tools for real-time control systems." In *Proceedings of the 2nd Workshop on Real-Time Tools*. Copenhagen, Denmark.

Cervin, A., D. Henriksson, B. Lincoln, J. Eker, and K.-E. Årzén (2003): "Analysis and simulation of controller timing." *IEEE Control Systems Magazine*. To appear.

Lincoln, B. (2002a): "Jitter compensation in digital control systems." In *Proceedings of the 2002 American Control Conference*.

Lincoln, B. (2002b): "A simple stability criterion for control systems with varying delays." In *Proceedings of the 15th IFAC World Congress*.

Lincoln, B. and B. Bernhardsson (2000a): "Efficient pruning of search trees in LQR control of switched linear systems." In *Proceedings of the Conference on Decision and Control*.

Lincoln, B. and B. Bernhardsson (2000b): "Optimal control over networks with long random delays." In *Proceedings of the International Symposium on Mathematical Theory of Networks and Systems*.

Lincoln, B. and B. Bernhardsson (2002): "LQR optimization of linear system switching." *IEEE Transactions on Automatic Control*, October. To appear.

Lincoln, B. and A. Cervin (2002): "Jitterbug: A tool for analysis of real-time control performance." In *Proceedings of the 41st IEEE Conference on Decision and Control*.

Lincoln, B. and A. Rantzer (2001): "Optimizing linear system switching." In *Proceedings of the 40th Conference on Decision and Control*.

Lincoln, B. and A. Rantzer (2002): "Suboptimal dynamic programming with error bounds." In *Proceedings of the 41st Conference on Decision and Control*.

Probing Control of Substrate Feeding in Biotechnical Processes

Lena de Maré

Start of project	1999-10-01
Plan	PhD 2004
Supervisors	Per Hagander, Björn Wittenmark
Course Credits	57
Publications:	2 conference articles, 2 technical reports, 2 journal articles

Research Problem and State of the Art

Today many proteins are produced by genetically modified microorganisms. One of the host organisms used is the bacterium *Escherichia coli*. During the cultivations the accumulation of the by-product acetate is a problem. Acetate reduces growth and protein formation, but it can be avoided if a proper substrate feeding strategy is used. This is hard to accomplish without considerable process knowledge.

Mats Åkesson has developed a feedback strategy using standard sensors. The key idea is to exploit a change in cell metabolism at the onset of acetate formation. By superimposing short pulses in the substrate feed rate, on-line detection of acetate formation can be made using the dissolved oxygen sensor. A feedback algorithm is used to adjust the feed rate to avoid acetate formation while maintaining at a high growth rate. There are other microorganisms that have a similar behavior when cultivated, which makes it reasonable to extend the work into these areas. Implementation into large scale production is also an important task. There is big interest in this area since it will increase the yield of the process and the reproducibility.

Goals

- To have a better understanding of the biotechnical processes and thereby making progress in the modeling of the system and take advantages of other and new sensors in the controller design.
- More large-scale experiments with the controller at Pharmacia Strängnäs.
- Investigation of temperature control of the dissolved oxygen in fed-batch cultivations.
- To learn more about complex media and how to control a complex feed.
- Experiments where feedback from acetic acid measurements are used to control the glucose feed.

Research Approach

I intend to make progress in the modeling of a bioreactor.
Experiments at Linköping university will be carried out using acetic acid measurements to control the feed. Since there are acetic acid measurements available continuously the pulse feeding strategy can be evaluated.
Also temperature control of the dissolved oxygen will be investigated together with the biotechnology department at LTH. Maybe the temperature control can be implemented in the pulse feeding strategy as a mean to avoid oxygen limitation when the stirrer speed has reached its maximum.
Together with Novozymes some initial investigations on how to feed a complex feed into a biorector might be done.
More large-scale experiments with the controller at Pharmacia Strängnäs will hopefully be carried out.
Other processes with microorganisms may also be studied. For example a process involving fungi at the department of Chemical Engineering LTH may be of interest.

Results

I have investigated feedback control of flow rate from a peristaltic pump using balance measurement together with S. Velut, M. Åkesson and P Hagander. Implementation in SattLine was done and some experiments were conducted to evaluate the system with equipment from the department of Biotechnology at LTH, [de Maré *et al.*, 2001]
Together with Stephane Velut two large-scale experiments at Pharmacia Strängnäs have also been done [Velut *et al.*, 2002]
I have investigated cultivations of *Vibrio cholerae* in lab-scale at Statens Bakteriologiska Laboratorium. The feeding strategy seemed to work also in this environment so I have implemented the controller in a software called Genesis.
I have written an article [de Maré *et al.*, 2003] concluding the experiments made at SBL.
I have investigated through simulations how to control the feed using feedback from acetic acid measurements [de Maré and Hagander, 2002].
I have also worked together with the biotechnology department on an article where the pulse feeding strategy is used, [Ramchuran *et al.*, 2003]

Milestones

Fall 2004 PhD

External Contacts

Universities

Linköpings universitet
Bioteknik, LTH

Industries

Statens Bakterologiska Laboratorium, Stockholm

Pharamcia, Stockholm

Course Work

I now have 57 credits. The courses I have finished are: Komplex Analys, Linjär Analys, Tools for Control, Controllability Analysis and Plantwide Control, Introduction course in Chemical Process Control, Linjära System, Computer Controlled Systems, Mathematical Modeling in Chemical Engineering, Syntes, Praktikfall i industrin, Realtime System, Optimisation, Modellering av bioreaktorer and pedagogisk introduktionskurs. I have also almost finished the course System Identification.

Service to the Department

Teaching

I have been a teaching assistant in the following courses

Course	**Last Taught**
AKM and lab in PR	Spring 2002
AKE and lab in AR	Fall 2001
AKM	Spring 2001
AKE	Fall 2000
Process Control	Spring 2000
AKE	Fall 1999

Publications

de Maré, L., L. Andersson, and P. Hagander (2003): "Probing control of glucose feeding in *Vibrio cholerae* cultivations." *Bioprocess and Biosystems Engineering*.

de Maré, L. and P. Hagander (2002): "Simuleringar och analys av v. cholerae odling där feeden styrs genom återkoppling från ättiksyramätningar," (Simulations and analysis of a v. cholerae cultivatyion where feedback from acetic acid measurements as used to control the feed.). Technical Report ISRN LUTFD2/TFRT–7600–SE. Department of Automatic Control, Lund Institute of Technology, Sweden.

de Maré, L., S. Velut, P. Hagander, and M. Åkesson (2001): "Feedback control of flow rate from a peristaltic pump using balance measurements." In *European Control Conference*.

Ramchuran, S., E. Nordberg Karlsson, S. Velut, L. de Maré, P. Hagander, and O. Holst (2003): "Production of heterologous thermostable glycoside hydrolases and the presence of host-cell proteases in substrate limited fed-batch cultures of escherichia coli bl21(de3)." *Applied Micro- and Biotechnology*.

Velut, S., L. de Maré, J. P. Axelsson, and P. Hagander (2002): "Evaluation of a probing feeding strategy in large scale cultivations." Technical Report ISRN LUTFD2/TFRT–7601–SE. Department of Automatic Control, Lund Institute of Technology, Sweden.

Batch Control and Diagnosis

Rasmus Olsson

Start of project	1999-10-01	**Plan**	PhD 2004
Supervisors	Karl-Erik Årzén	**Course Credits**	60
Publications:	4 conference articles.		

Research Problem and State of the Art

The aim of this project is to study integrated information and control systems for batch production. Special emphasis will be put on integration of the monitoring and supervision tasks with recipe-based production.

A batch control system must support a large number of functions in addition to the basic regulatory control. Some examples are production planning, production scheduling, recipe management, resource arbitration and allocation, batch report generation, unit supervision, and exception handling. Exception handling is a critical element for achieving long-term success in batch production. Some examples of exception handling situations could be: “A valve that fails to respond to an “Open” or “Close” command.”, “A recipe that requires a shared resource which is already in use.”, or “An emergency stop that must be performed due to a potentially hazardous situation.” Correct handling of exceptions of these type is a key element in process safety, consistent product quality, and production cost minimization.

Recently a lot of focus has been put on standardization of the models and terminology used in batch control, e.g. NAMUR and S88. However, so far very little has been specified in the area of exception handling.

In most cases batch production is repetitive in nature. Information from previous batches may be used to improve control and monitoring of the current and future batch. Often there is an interaction between the controller and the diagnostic system. The use of historical data will hopefully make the separation of the two easier.

Goals

- Study the interaction between recipe execution and supervision. A model-based approach will be taken where an internal unit model is used to check the validity of the unit operations in the recipes online.
- Investigate the usage of historical data in monitoring and supervision of batch processes. In most cases batch production is repetitive in nature. Information from previous batches may be used to improve control and monitoring of the current and future batch.

Research Approach

The research will aim to extend the work on Grafchart, a Grafcet-related language for sequential programming, to also include exception handling. Grafchart is implemented in G2 from gensym Corp, and is currently being re-implemented in Java, JGrafchart, using a Swing-based graphiccs library from Northwoods Software Corp called JGo.

Results

An internal model approach for exception handling is proposed in [Olsson and Årzén, 2000] and [Olsson and Årzén, 2002]. Each equipment unit is represented by a state machine-based model that is used on-line to structure and implement the safety interlock logic, and to provide a safety check to ensure that recipe operations are performed in a correct order. The approach has been implemented in JGrafchart and tested on the Procel pilot plant at the Department of Chemical Engineering at UPC, Barcelona, Spain.

A batch process laboratory exercise has been developed from scratch [Olsson *et al.*, 2002]. The students use JGrafchart to control the process.

A description of how Grafchart can be used for operator support is found in [Årzén *et al.*, 2002].

Milestones

Fall 2002	Complete Licentiate Thesis.
Spring 2003	Develope methods for fault diagnosis using historical data.
Fall 2004	Complete Doctoral Thesis

External Contacts

Universities

Within the Center for Chemical Process Design and Control(CPDC) graduate school contacts with Chalmers University of Technology and Royal Institute of Technology has played an important part. The Technical University of Catalonia (UPC) in Barcelona, Spain

Industries

Eka Chemicals AB and ABB Automation Products.

Course Work

Since the start of the project I have studied: “Developement of a Laboratory Exercise”*, “Embedded Systems and Real-time Control”*, “System Identification”*,

"System Identification Graduate Course"*, "Pedagogisk Introduktionskurs", "Process Analysis and Optimisation", "Control System Synthesis", "Bluetooth in Industry", "Languages for Automation", "Praktikfall i Reglerteknik", "Pedagogisk Introduktionskurs", "25 Seminal Papers in Control Theory", "Optimization", "G2-390: Intermediate and Advanced G2 Training", "Real-Time Systems", "Computer Controlled Systems", "Tools for Control", "Linear Systems", "Adaptive Control"*, "Chemical Process Control", "Mathematical Modeling", "Hybrid Systems", and "Controllability Analysis and Plantwide Control". Courses marked with a '*' are not completed.

I now have 60 credits. At the end of this year I intend to have 70 credits.

Service to the Department

Teaching

I have been teaching assistant in the following courses

Course	Last Taught
Real Time Systems	Fall 2002
Processreglering	Spring 2002
AK(FDI)	Fall 2000
AK(M)	Spring 2000
AK(FD)	Fall 1999

Publications

Olsson, R. and K.-E. Årzén (2000): "Exception Handling in Recipe-Based Batch Control." In *Proc. of ADPM2000 The 4th International Conference on Automation of Mixed Processes.* Dortmund, Germany.

Olsson, R. and K.-E. Årzén (2002): "Exception Handling in S88 using Grafchart." In *Proc. of World Batch Forum North American Conference 2002.* Woodcliff Lake, NJ, USA.

Olsson, R., H. Sandberg, and K.-E. Årzén (2002): "Development of a Batch Reactor Laboratory Process." In *Reglermötet 2002.* Linköping, Sweden.

Årzén, K.-E., R. Olsson, and J. Åkesson (2002): "Grafchart for Procedural Operator Support Tasks." In *Proceedings of the IFAC World Congress, Barcelona, Spain.*

Industrial Aspects of On-line Monitoring and Diagnosis

Mikael Petersson

Start of project	1998-10-01	**Plan**	PhD 2003
Supervisor	Karl-Erik Årzén, Tore Hägglund	**Course Credits**	62
Publications:	4 Conference Articles.		

Research Problem and State of the Art

The process industry of today is highly automated. The control loops outnumbers by far the number of operators and people in the maintenance and instrumentation departments. The processes to control are getting more complex, but the control problems are still attacked with mostly PI-controllers. With this in mind, it would be desirable to have a tool for analyzing control loops. The goals are to determine whether the loops are well tuned, to verify if an appropriate control strategy has been chosen, and, when not, to get a measure on how much better control is achievable using another control strategy.

The project concerns monitoring and auditing simple control loops. SISO loops with an extra measurable signal are considered. The first step is to establish the relation between the control loop and the extra signal, then how to use this signal to achieve better control. Finally a measure on how much better control that can be obtained is desirable preferably weighted with the complexity of the control strategy chosen.

Goals

- Characterize extensions of the simple feedback loop (cascade, feedforward, ...).
- Establish feedback loop behaviour due to different disturbances,
- A method for assessing a measurement with respect to usage in a feedforward control action has been developed,
- A method for assessing a measurement with respect to usage in the inner loop of a cascade controller has been developed,
- Develop an scheme for assessment of signals in a combination of FF and cascade control.
- Compare the information obtained from the above metrics with that of Harris-like indices,
- Look into evaluation of metrics when gain scheduling is used or could be used.

Research Approach

A survey of control strategies and structures will give insight in the fundamental properties of the systems in consideration. Initially a basic SISO system is investigated. It consists of a simple feedback loop with a serie of first order processes. The effects of different entry points of some types of disturbances is studied. These disturbances are evaluated as potential candidates for feedforward control. Further on systems that can be found in the process industry will be subject for the project.

The tool-set used consists so far of a method which supports making the decision to add feedforward control action from an additional signal. The computer tools used are Matlab, Simulink, and an implemetation in Java.

The industrial partner is able to provide real process knowledge and data, and furthermore real experiments can hopefully be performed. The method(s) are being implemented in ABB's new control system *Control*$^{\mathrm{IT}}$.

Results

- Literature study on diagnostics
- Study of on-line change detection methods
- Literature study of control performance assessment
- A measure for assessing the possibility and benefit of introducing feedforward control
- Development of tools in Matlab/Simulink
- Patent application for the feedforward index
- Implementation of the results in real-time Java
- A measure for assessing the possibility of introducing cascade control
- Implementation ongoing of the results in ABB's control system product Control^{IT}

Milestones

Mid 2000	Conference paper on assessing possible candidates for feedforward control.
Fall 2000	Filing patent application.
Late 2000	Implementing the ideas in Java.
Summer 2001	Running experiments on laboratory processes
2001	Extending the ideas to more control structures.
Fall 2002	Started writing my PhD thesis
Early 2003	PhD thesis ... end of project

External Contacts

The major industrial partner in this project is ABB. Early 2001 I changed employer from ABB Corporate Research to ABB Automation Technology Products. During the project cooperation with other ABB companies, partners, and the pulp and paper industry will take place.

In the spring 1999, I attended a COSY course on Fault Tolerant Methods in Control and Automation. The course was organized by the department of Control Engineering at Aalborg University.

In October 1999 a course on Controllability Analysis and Plantwide Control was attended at Norwegian Institute of Science and Technology.

The spring 2000, my related work at ABB has resulted in visits to LiTH, closed-loop identification, and KTH, control structure selection based on rigorous models, and control-loop performance assessment.

In June 2001 I gave a seminar about my research at Division of Automatic Control at Linköping University.

Universities

Aalborg University, Denmark (Dept. of Control Engineering)

Linköping University, Sweden (ISY, Automatic Control)

Royal Institute of Technology, Sweden (S^3, Process Control)

Industries

ABB Corporate Research, Sweden and Geremany.

ABB Automation Technology, Sweden.

AssiDomän Corporate R & D, Sweden (the group is now at Optimation AB)

Course Work

- Course credits today: >62
- Course credits by end of year (estimated): 70

Service to the Department

This section does not apply to me as an industrial PhD student. I have however volunteered to participate in some education related to my field of research.

Teaching

I have been teaching assistant in the following courses

Course	Last Taught
Real-Time Systems	Fall 2000
System Identification	Spring 1999

Administrative Duties

- None

Others

During the fall 2000 I supervised PhD-students in the Real-Time Systems course. During the spring 2001 I merged and further developed the result of two groups. One part of this will be used in virtual laboratory experiments in the Real-Time Systems course during fall 2001.

During spring 1999 the assistants of System Identification in cooperation with the research engineers conducted major course development

- laboratory exercises has been transferred to Linux/Simulink-environment, and
- the Pendubot has been made available as a laboratory process.

Publications

Petersson, M. (2002): "Measurement based control structure assessment of ordinary control loops." In *Preprints Reglermöte 2002*. Linköping, Sweden.

Petersson, M., K.-E. Årzén, and T. Hägglund (2001): "Assessing measurements for feed-forward control." In de Carvalho, Ed., *ECC 2001*. Porto, Portugal.

Petersson, M., K.-E. Årzén, H. Sandberg, and L. de Maré (2002a): "Implementation of a tool for control structure assessment." In *Proceedings of the 15th IFAC World Congress*. Barcelona, Spain.

Petersson, M., L. Pernebo, B. hansson, K.-E. Årzén, and T. Hägglund (2002b): "Control structure assessment in an industrial control system." In *Control Systems 2002*. Stockholm, Sweden.

Modeling and Control of Time-Varying Systems

Henrik Sandberg

Start of project	2000-01-03
Plan	PhD 2005
Supervisors	Anders Rantzer & Björn Wittenmark
Course Credits	60+
Publications:	7 conference papers and 1 journal publication.

Research Problem and State of the Art

Systems with periodic dynamics, or more generally with time-varying dynamics, are often obtained from modeling of physical systems. Systems with time-varying parameters are one such example. Another example—and perhaps a more common one—is when when linearizing non-linear systems of differential equations around a trajectory. This results in time-varying linear systems, even when the non-linear equations are time-invariant. We have at the department studied locomotives with non-linear power electronics. Linearization along the periodic current and voltage trajectories has been proven to be successful in stability and robustness analysis. The harmonic interaction that is well described by linear periodic models is believed to be the cause of real-world power breakdowns.

There has been many different approaches to analysis and controller synthesis for time-varying systems. Often the aim has been to generalize results for time-invariant systems. Classical results along these lines are those of *Floquet* and *Hill* (19th-century scientists) for periodic systems. Their work has been further generalized into the so-called *lifting* methods. Frequency-domain lifting methods such as the harmonic transfer function, see *Wereley* and *Möllerstedt*, has been tested by us and works well in practice. Time-domain lifting has also been developed, see for example *Bamieh et al.* or *Lall et al.* for two different versions. Lifting methods use operator theory to a large extent.

Goals

There are many practical and theoretical questions that remain unanswered, some goals to obtain are:

- Balanced truncation, a well-known model-reduction technique for time-invariant systems, should be generalized into the time-varying framework.
- The possibilities for modeling, approximation, and reduction of chemical reaction systems using linear time-varying techniques should be studied.
- Modeling and analysis of non-linear power electronic components using linear time-periodic models should be further developed.

- Generalizations of some time-invariant results into the time-varying setting should be made, for instance an equivalent to the Bode-integral.

Research Approach

The use of balanced truncation on chemical reaction models should be evaluated, along with development of efficient numerics. A 28th-order model of a diesel exhaust catalyst has been obtained from partners within CPDC.

The work on modeling of power components is continued, hopefully in co-operation with Bombardier Transportation in Västerås.

The time-varying system we study are supposed to be linear. For balanced truncation we assume there is a finite-dimensional state-space realization and use Lyapunov theory. For stability and robustness analysis we use the harmonic transfer function, which does not require finite-dimensional realizations but instead uses operator theory and complex analysis.

Results

In the master thesis [Sandberg, 1999] a model of the motor side of an inverter locomotive using linear time-periodic techniques was made. The work gave insight in the behavior of asynchronous motors, power converters and pulse width modulation. The work resulted in two conference papers [Sandberg and Möllerstedt, 2000a, Sandberg and Möllerstedt, 2000b]. A conference paper that summarizes much of the periodic power modeling done at the department is [Sandberg and Möllerstedt, 2001].

More recently balanced truncation of time-varying systems has been studied. We have obtained upper and lower error bounds on truncated models, and proven that input-output stability is preserved in the truncation process. We have started to apply the results to chemical reaction models and have obtained promising initial results. This work is presented in the two conference papers [Sandberg and Rantzer, 2002a, Sandberg and Rantzer, 2002b]. The work is summarized in an article submitted for journal publication.

Milestones

Fall 2002	Licentiate completed and journal article submitted.
Spring 2003	Evaluation of time-varying modeling.
Fall 2003	80% finished.

External Contacts

My master thesis was made in co-operation with Adtranz (now Bombardier Transportation) and ABB Corporate Research. Erik Möllerstedt, formerly in the project, is now working for Decuma AB in Lund. Our postdoc Chung-Yao Kao from MIT is now also working with power system modeling and analysis.

I spent March until June 2001 at Caltech in Pasadena, USA, working in a group led by Prof. Richard Murray. The project concerned multi-vehicle control.

I'm partially financed by the CPDC-project with members from Royal Institute of Technology, Chalmers, and Lund Institute of Technology. We received a diesel exhaust catalyst model from Björn Westerberg, now working for Scania.

Universities

California Institute of Technology Pasadena Richard Murray

Industries

Bombardier Transportation Västerås Johann Galic

Course Work

I now have 60 credits. At the end of this year I intend to have about 70 credits.

Service to the Department

Teaching

I have been teaching assistant in the following courses

Course	Last Taught
Real-Time Systems	Autumn 2002
Nonlinear Control and Servo Systems	Spring 2002
AK(M)	Spring 2001
AK(FED)	Autumn 2000

Initiatives

Rasmus Olsson and I were involved in the development of a new batch reactor laboratory exercise.

Administrative Duties

I am the PhD-students' representative in the department council.

Publications

Ghulchak, A. and H. Sandberg (2002): "Book review: Computer control systems. Analysis and design with process-oriented models, by E. Rosenwasser and B. Lampe." *Automatica*, **38**, October, pp. 2031–2035.

Olsson, R., H. Sandberg, and K.-E. Årzén (2002): "Developement of a batch reactor laboratory process." In *Proc. of Reglermöte 2002, Linköping*, pp. 31–35.

Petersson, M., K.-E. Årzén, H. Sandberg, and L. de Maré (2002): "Implementation of a tool for control structure assessment." In *Proceedings of the 15th IFAC World Congress*. Barcelona, Spain.

Sandberg, H. (1999): "Nonlinear modeling of locomotive propulsion system and control." Technical Report Masters thesis ISRN LUTFD2/TFRT–5625–SE. Department of Automatic Control, Lund Institute of Technology, Sweden.

Sandberg, H. and E. Möllerstedt (2000a): "Harmonic modeling of the motor side of an inverter locomotive." In *Proc. of Reglermöte 2000*. Uppsala, Sweden.

Sandberg, H. and E. Möllerstedt (2000b): "Harmonic modeling of the motor side of an inverter locomotive." In *Proceedings of the 9th IEEE Conference on Control Applications*. Anchorage, Alaska.

Sandberg, H. and E. Möllerstedt (2001): "Periodic modelling of power systems." In *Proceedings of the IFAC Workshop on Periodic Systems and Control*. Cernobbio-Como, Italy.

Sandberg, H. and A. Rantzer (2002a): "Balanced model reduction of linear time-varying systems." In *Proceedings of the 15th IFAC World Congress*. Barcelona, Spain.

Sandberg, H. and A. Rantzer (2002b): "Error bounds for balanced truncation of linear time-varying systems." In *Proceedings of the IEEE Conference on Decision and Control*. Las Vegas, Nevada.

Modeling and Control of the Drying Section of a Paper Machine

Ola Slätteke

Start of project	2001-01-15
Plan	PhD 2006
Supervisor	B Wittenmark, T Hägglund and K Forsman
Course Credits	23
Publications:	1 conference article

Research Problem and State of the Art

The drying section of a paper machine can consist of up to one hundred drying cylinders and have a total length of more than 100 meters. Compared to other parts of a paper machine the drying section is the most expensive one in terms of energy use and investment costs per kilogram removed water.
One way to increase the production rate in a paper machine is to increase the amount of paper that has acceptable quality. The produced paper must fulfil product specification with respect to basis weight, moisture content and physical properties. One of the reasons for loss in production capacity is due to grade changes in the paper machine during which many parameters change as machine speed, basis weight and pulp quality.
From a control point of view it is very important to have good dynamical process models. These models will be used to determine the structure of the control system as well as the tuning of specific controllers. Some of the main issues concerning the control loop performance in the drying section are couplings between different sub-processes.
Dynamic models of the drying section have been developed in a number of projects through the years. The goal of this project is to proceed along these lines with respect to dynamical modelling, validation and control of industrial paper machines.

Goals

- Develop and evaluate models for the drying sections of the paper machine.
- Develop and investigate different control schemes and tuning rules for the drying section of the paper machine.

Research Approach

A bottom-up approach is used in this project and I have first investigated the inner steam pressure control loops in the drying section of a paper machine. These loops play an important role for the quality of the moisture control, which is the outer loop in this cascade control. Much emphasis is also put on the understanding of the origin of disturbances that have been seen in measurements on many industrial paper machines. Some of the tools that are used are Matlab and Modelica.
This project is carried out in close collaboration with ABB Industries AB within their industrial projects concerning optimization of drying sections of paper machines. It is also strongly integrated with the drying group at the Department of Chemical Engineering, Lund Institute of Technology, who has a long experience of physical modeling.

Results

- A tuning rule for the steam pressure controller in the cylinders, based on four process parameters that can be obtained from a simple step response.
- Practical experience from several paper mills and a more profound comprehension of the drying process.

Milestones

Fall 2003	Licentiate Thesis
Spring 2006	PhD

External Contacts

- ABB Industries AB
- Department of Chemical Engineering, Lund Institute of Technology
- Different paper manufacturers around Sweden, such as Assi Domän and Stora Enso

Course Work

I now have 23 credits. At the end of this year I intend to have 35 credits.

Publications

Slätteke, O., K. Forsman, T. Hägglund, and B. Wittenmark (2002). "On Identification and Control Tuning of Cylinder Dryers.", *Control Systems '02, Stockholm, Sweden, 2002.*

Nonlinear and Hybrid Control Strategies

Stefan Solyom

Start of project	1999-8-01	**Plan**	PhD 2004
Supervisors	Anders Rantzer		
Course Credits	20+8		

Research Problem and State of the Art

Development of new methodology for nonlinear and hybrid control referring to the benchmarks of the ESPRIT H2C Heterogeneous Hybrid Control Project (ABS, 4 wheel steering, speed control of lorries).

Goals

To develop methods to identify, analyze and synthesize control trajectories in nonlinear and hybrid systems.

Research Approach

Initially, we will use simulation, optimal control software and convex optimization techniques to find critical trajectories and evaluate a nonlinear control design.
The aim is to later use the results to improve the controllers.
Relations to the approaches such as extremal seeking control, adaptation, computational performance evaluation and design, piecewise linear models, MPC will be considered.

Results

Developed an MPC Controller in Matlab, which is using an on-line C optimization code.
Developed an extremal seeking controller for the ABS system.

Milestones

- Literature study
- Computational performance evaluation of the existing designs on the mentioned benchmarks

External Contacts

My work was financed by the ESPRIT H2C Heterogeneous Hybrid Control Project. Within the frame of this project I have been disscusing with Jens Kalkkuhl from our partner Daimler Chrysler.

Course Work

I now have 20 credits and 2 on-going courses for 8 credits. I am attending Swedish Language Courses at Folksuniversitetet and completed 4 levels.

Service to the Department

Teaching

I have been teaching assistant in the following courses:

Course	Last Taught
Adaptiv Reglering	Fall 1999
System Identification	Spring 2000

Administrative Duties

- I don't have any administrative duties, yet.

Publications

Solyom, S. and A. Ingimundarson (2002): "A synthesis method for robust pid controllers for a class of uncertain systems." *Asian Journal of Control*.

Solyom, S. and A. Rantzer (2002a): *ABS control — A design model and control structure*.

Solyom, S. and A. Rantzer (2002b): "The servo problem for piecewise linear systems." In *Proceedings of the Fifteenth International Symposium on Mathematical Theory of Networks and Systems*.

Research And Implementation Of Electrically Actuated Brake System For Heavy Vehicle

Jacob Svendenius

Start of project	2001-02-01
Plan	PhD 2005
Supervisor	Björn Wittenmark, Per Hagander
Course Credits	80

Research Problem and State of the Art

This project will deal with brake systems for heavy vehicle. These systems have since long time used compressed air as control and energy source. The tendency nowadays is that most of the automotive company tries to exchange mechanical and fluid system for electric system. So even the pneumatic braking system. New trucks have a so called EBS system, where a computer sends electric signals to control the brakes. The signals only control the valves and the applying force still comes from pressure air. Probably in the future electricity power will replace the air even there. It would result in a faster and more precise system. Thereby it opens the door for research about more intelligent safety system. Even while it will be easier to to integrate more sensors on the vehicle it is not possible or economically profitable to measure all signals that are necessary for better safety systems. This point of view has lead this project into studying tire models. Knowledge about the tire dynamics will be more important when the brake regulator gets faster. Having an optimal brake performance the limits for safe driving will be in the tire friction. A safety system can work better if it knows the actual limits of the road/tire interaction. One of the problems stated in this project is how to determine the limits of the braking force without reaching the limit region. A lot of research is going on in this area. The main part of it is done at the automotive companies and is then also strictly confidential. The university in Grenoble (France) is working on friction observation with the LuGre-friction model. The work of H. B. Pacejka from Delft university has inspired this project a lot. The methods exist but they have to be better and more reliable.

Goals

The main target with this project is to improve functions of a brake system. Therefore we need to gain knowledge about how to mathematically describe

the influence of tire properties like dynamics and friction. From that we try to develop tools to measure or estimate the properties that are important features for the brake system.

Research Approach

The approach has been to use existing theory about the friction development in a tire and then by simplifying the model in an appropriate way be able to estimate the friction by using recursive least squares or maybe a nonlinear estimation algorithm. The problem is complex and it is necessary to be able to describe the behavior in one region while measuring in another. This puts demand on the number of degrees of freedom in the model. It must be carefully chosen. It is necessary to do vehicle tests to determine the quality of the needed signals and adjust the estimation from that. All calculations will be done in matlab.

Results

- A model of the wheel , axle and tire-road friction together with brake unit has been done
- Literature study has been done and a review written about tire models and friction
- A couple of tire friction models with different degrees of freedom have been established.

Milestones

Fall 2002	Conclude literature study regarding tire models
Spring 2003	Vehicle test performed to validate proposed tire models.

The project took a change in concentration in May 2002. From concerning brake control and dynamics we decided to focus more on the system side. This will hopefully later on include brake control, but from another point of view. That is why it is hard to say weather the previous milestones have been achieved or not.

External Contacts

This project is a cooperation between the Department of Automatic Control at Lund Institute of Technology and the company Haldex Brake Products in Landskrona. A contact with the Department of Automatic Control in Grenoble has recently been established. Maybe that will result in a collaboration on friction estimation in the future.

Universities

Lund University

Industries

Haldex Brake Products AB

Course Work

I now have 48 credits. At the end of this year I intend to have 53 credits.

Service to the Department

Teaching

Course	Last Taught
AK(M)	Spring 2002

Administrative Duties

This project is paid by the industry and there is no administrative duty included.

Modeling of Thermo-Hydraulics

Hubertus Tummescheit

Start of project:	1996-04-15	**Plan:**	PhD finished 30/8 2002
Supervisor:	K. J. Åström, A. Rantzer	**Course credits:**	81
Publications:	3 Journal Articles, 9 Conference Articles		

Research Problem and State of the Art

Object oriented modeling has been a research topic in Lund for a long time: Dymola, Omola, the K2 libraries and finally the Modelica language effort. Object oriented modeling libraries have quite a success in mechatronics, but they are not used much in thermodynamics. Two main reasons for that are the lack of reusable medium property routines and a lack of robust models. Our industrial partners have expressed interest in physical models for their application domains, but earlier models mainly lacked "robustness" for industrial day-to-day use. This also calls for better integration between control engineering tools and design tools. With the ongoing development of the Modelica language (syntax extensions to PDE, standardized API for simulation) these problems can be addressed well. The Modelica language also offers new possibilities to use different classes of physical models as class parameters to the same plant model. For thermo hydraulic and process engineering models this offers a new level of model reuse.

Dynamic simulation packages for thermodynamic systems (power plants, refrigeration equipment, combustion engines, heat exchanger networks, pipeline systems for gas and oil, district heating networks, HVAC systems) are usually

1. only for a specific application domain (APROS, Sinda/Fluint, TRANSYS, Aspen Dynamics),
2. lack interfaces for interaction with other software,
3. do not allow to couple the models with models from another domain, e.g. an engine model to a transmission model.
4. not designed with respect to solving control problems.

Some of these packages have very efficient numerical solvers, which are needed for simulating large plants, but they are specialized and restricted to narrow problem classes.

Goals

Design and implement a well validated, easy to use model library for the dynamic simulation of thermo-hydraulic processes, ThermoFluid. The library should be applicable to the physical model layer of all the above application domains and cover models both for design simulation and control design. The efficiency and

the accuracy of the solution should be comparable to special purpose packages. The models should fulfill two main requirements:

- be *reusable* for many applications,
- be *robust*, i. e. work even with incomplete knowledge about boundary and initial conditions and certain parameters.

The generic model constructs of the modeling language Modelica are extensively used to implement the ThermoFluid library.

Research Approach

Within the development of the Modelica language my main interests are

- structuring of large csale, physical models,
- language constructs for generic models,
- modeling of distributed processes and PDE,

The current results and the ongoing development of the Modelica language are then used and tested with the thermo-hydraulic library design.

- Main items of the current work are:
  - extend the existing library structure
  - implement the physical base models
  - validate them in industry projects
- The main tools are:
  - Physical modeling
  - Object oriented design techniques
  - Modelica language, Dymola
  - Computer algebra tools: Mathematica and Maple

Results

- A model library for thermohydraulics inplemented in Modelica, ThermoFluid.
- At the Ford Research Lab, showed feasibility of developing high-fidelity models for engine and powertrain simulation, including combustion and emission models.
- In cooperation with United Technologies Research Lab and International Fuel Cells, demonstrated the increase of modeling productivity with object-oriented model libraries for systems modeling of fuel cells. The ThermoFluid library is used as a base for the modeling of complex fuel cell systems including the fuel reformation.
- Developed and enhanced different type of models for two phase flow for the Modelica ThermoFLuid Libraries.

External Contacts

Universities

DTU Lyngby:	Jacob Munch Jensen, Arne Jakobsen.
Linköping TH:	Peter Fritzsson
TU Hamburg Harburg	Gerhard Schmitz, Torge Pfafferott
TU Berlin	Stefan Jähnichen.

Industries

ABB Research Lab Heidelberg:	Rüdiger Franke
Dynasim AB:	Sven Erik Mattsson, Hilding Elmqvist.
Ford Motor Company, Scientific research Lab:	Michael Tiller, George Davis.
International Fuel Cells:	Eric Rohrbach, Tim Crowley
Sydkraft Konsult AB:	Martin Råberg
Tetrapak AB:	Tomas Skoglund
Toyota Motor Company	Akira Ohata, Toshihiro Nagai
United Technologies, Research Lab:	Clas Jacobsen, Lars Malcolm Pedersen, Jonas Ebo

Service to the Department

Teaching

I have been teaching assistant in the following courses

Course	Last Taught
AK(M)	Spring 1999, 2001
AK(FED)	Fall 1999, 2000, 2002
Robotics	Fall 2002

Administrative Duties

- Taking care of the Modelica design group web-site.
- Organisation of the Modelica 2000 Workshop in Lund.
- Compilation of the research abstracts 2002 (this document).

Master Thesis Supervision

- Olaf Bauer, Spring/Summer 1999.
- Alessandro Pontremoli, Fall 2000.
- Antonio Gomez, Spring 2001.

Publications

Bauer, O. and H. Tummescheit (2000): "Modeling of two-phase flows in modelica." In *Proceedings of the 3rd MATHMOD Conference, MATHMOD 2000*. IMACS, Vienna.

Eborn, J., H. Tummescheit, and K. J. Åström (1999): "Physical system modeling with Modelica." In *Proc. of the 14th World Congress, IFAC'99*, vol. N. IFAC.

Hahn, W. and A. Lehmann, Eds. (1997): *Proceedings of the 9th European Simulation Symposium ESS97*, Budapest, Hungary. Society for Computer Simulation International.

Munch Jensen, J. and H. Tummescheit (2002): "Moving boundary models for dynamic simulations of two-phase flows." In Otter, Ed., *Proceedings of the 2nd International Modelica Conference 2002*, pp. 235–244. Oberpfaffenhofen, Germany.

Sydow, A., Ed. (1997): *Proceedings of the 15th IMACS world congress on Scientific Computation, Modelling and Applied Mathematics*, vol. 6, Berlin, Germany. Wissenschaft und Technik Verlag.

Tiller, M., C. Davis, H. Tummescheit, and N. Trigui (2000): "Powertrain modeling with modelica." In *Prooceedings of IMECE2000, 2000 ASME International Mechanical Engineering Congress and Exposition*. ASME.

Tummescheit, H. (2000a): "Object-oriented modeling of physical systems, part 11." *Automatisierungstechnik*, **48:02**.

Tummescheit, H. (2000b): "Object-oriented modeling of physical systems, part 12." *Automatisierungstechnik*, **48:04**.

Tummescheit, H. and J. Eborn (1998a): "Design of a thermo-hydraulic model library in Modelica." In Zobel and Moeller, Eds., *Proc. of the 12th European Simulation Multiconference, ESM'98*, pp. 132–136. SCS, Manchester, UK.

Tummescheit, H. and J. Eborn (1998b): "Developing a thermo-hydraulic base library in Modelica." In *Preprints of Reglermöte '98*, pp. 221–225. Lund Institute of Technology, Sweden.

Tummescheit, H. and J. Eborn (2002): "Chemical reaction modeling with thermofluid/mf and multiflash." In Otter, Ed., *Proceedings of the 2nd International Modelica Conference 2002*, pp. 31–41. Oberpfaffenhofen, Germany.

Tummescheit, H., M. Klose, and T. Ernst (1997): "Modelica and smile – a case study applying object-oriented concepts to multi-facet modeling." In Hahn and Lehmann, Eds., *Simulation in Industry*, pp. 122–126. Society for Computer Simulation International, Budapest, Hungary.

Tummescheit, H. and R. Pitz-Paal (1997): "Simulation of a solar thermal central receiver power plant." In Sydow, Ed., *Proceedings of the 15th IMACS world congress on Scientific Computation, Modelling and Applied Mathematics*, vol. 6, pp. 671–676. Wissenschaft und Technik Verlag, Berlin, Germany.

Control of Biotechnological Processes

Stéphane Velut

Start of project	2001-01-03
Plan	PhD 2005
Supervisor	Per Hagander, Anders Rantzer
Course Credits	55
Publications:	1 conference article.

Research Problem and State of the Art

In most control problems the regulator task is to follow some specified reference trajectory. Several design methods are available to get good performance and robustness. In some cases like in extremum control, the objective is also to find a suitable reference value to drive the system near the optimal operating point. In E. coli cultivations the best operating point corresponds to the limit of the respiration capacity of the cells: the feed rate should be high without exceeding an unknown critical level above which by-products are produced. This means that the process should be controlled close to a saturation, a situation similar to the extremum control problem.

A probing strategy based on a pulse technique has been developped by Mats Åkesson. It consists in superimposing short pulses in the feed rate and observe the response in the dissolved oxygen signal. A feedback algorithm adjusts the feed rate to avoid overfeeding while maintaining a high glucose supply.

In fed-batch cultivations the probing controller operates most part of the time at the maximum stirrer speed. The feeding strategy should then be able to handle the limitation of the oxygen transfer capacity of the reactor.

Goals

The goal of the project is to derive control strategies for a class of nonlinear systems with the same structure as the bioreactor model. A short-term plan is to analyse the performance and the robustness of the existing probing controller for further improvements.

Modifications of the feeding strategy at the maximum stirrer speed are also to be done. The feed rate or the temperature can be used as control signal to maintain a constant dissolved oxygen level after saturation of the agitation speed.

Research Approach

The class of nonlinear systems to be studied is composed of a linear dynamic block in cascade with a static non-linearity (saturation) and another linear dynamic block. Only the output of the last block is available for measurement.

The probing controller can be viewed as an extremum controller. Information about the gradient is obtained by correlating the output with a known perturbation introduced at the input.

When the nonlinearity is piecewise affine, the problem can be formulated in a piecewise linear system framework. Linear matrix inequalities can be solved for analysis of the closed-loop system.

Results

Analysis of the probing control strategy has been carried out for linear systems with an input nonlinearity. When the nonlinearity can be well approximated by a piecewise affine function, stability can be checked by solving suitable linear matrix inequalities. Some robustness results with respect to uncertainty in the plant have also been derived.

The performance of the probing strategy in large scale cultivations has also been evaluated. The results were satisfactory and no major difficulties related to the scale have been encountered.

Milestones

Fall 2003	60 % Finished
Spring 2005	PhD Thesis

External Contacts

The project is done in cooperation with

Universities

Department of Biotechnology

Lund Institute of Technology

Industries

Pharmacia & Upjohn

Stockholm

Course Work

I now have 55 credits. At the end of this year I intend to have 65 credits.

Service to the Department

Teaching

I have been teaching assistant in the following courses

Course	Last Taught
AK(E)	Fall 2001
Systems Engineering	Spring 2001
AK(I)	Fall 2000

Publications

de Maré, L., S. Velut, P. Hagander, and M. Åkesson (2001): "Feedback control of flow rate from a peristaltic pump using balance measurements." In *European Control Conference*.

Velut, S., L. de Maré, J. P. Axelsson, and P. Hagander (2002): "Evaluation of a probing feeding strategy in large scale cultivations." Technical Report ISRN LUTFD2/TFRT–7601–SE. Department of Automatic Control, Lund Institute of Technology, Sweden.

Support for State Transitions in Chemical Process Industry

Johan Åkesson

Start of project	2001-01-01	**Plan**	PhD 2005
Supervisors	Karl-Erik Årzén	**Course Credits**	34
	Per Hagander		
Publications:	5 conference articles		

Research Problem and State of the Art

The research will be conducted in the field of chemical process control. Typically, chemical processes are designed and optimized for steady state operation. Also, processes are often controlled by local controllers. This setup leaves, in many cases, to the operators to manage situations as start ups, fault handling and changes of the product quality (grade changes). Efficient handling of production transitions is critical in a competitive business environment, where the demand is turning to diversification and tailored products. Operator support for grade changes is therefor of primary interest.

Advanced techniques like Dynamic Matrix Control and Model Predictive Control have established themselves as major control strategies in the chemical process community in recent years. However, there is less work done on control of dynamic and transient phenomena (for example start-ups and grade changes) and more work towards a unified framework including control, optimization and production planning remains to be done.

As a second field of research, control of unstable systems subject to input saturation is considered. Such problems are common in practice, since the available control authority is always limited. Applications range from inverted pendulums to fighter aircrafts.

Goals

- Develop techniques for control of transient phenomena in the process industry like grade changes, using optimization and model predictive control.
- Develop a software toolbox (G2 / Java) for Decision Support Structures for the CHEM project.

Research Approach

The approach that will be investigated is to use model predictive control and optimization to generate set point trajectories. The set point trajectories will be

represented as sequences of control actions and executed within a toolbox for handling of operator procedures. The toolbox will be based on Grafchart.

Within the CHEM project there is expected to be collaboration with other partners, both academic and industrial. This may include access to laboratory equipment for testing of proposed control techniques. An important part of the work in the CHEM project will be devoted to implementing a software toolbox for Decision Support Structures. The development tool for the toolbox is likely to be JGrafchart.

Milestones

Fall2002	MPC pre-study finished
Fall 2003	Licentiate Thesis
Fall 2005	PhD

External Contacts

I am partially financed by the CHEM project, where several European universities and industries participate.

- Participation in the course "Introduction to G2" given in Paris 18:th to 22:th June 2001 by Gensym Corp.
- Visits to UCSD, UCLA, Cal Tech and UCSB in August 2001.

Course Work

I now have 34 credits. At the end of this year I intend to have 45 credits.

Service to the Department

Teaching

I have been teaching assistant in the following courses

Course	Last Taught
Systems Engineering	Spring 2001
Automatic Control Basic Course (E)	Fall 2001
Systems Engineering	Spring 2002
Real Time Systems	Fall 2002

Administrative Duties

- Seminar announcer and responsible for reservations of the seminar room (2001-).

Others

- Co-developed the course “Systems Engineering”, Spring 2001.

Publications

Åkesson, J. and K.-E. Årzén (2002): “A frame work for process state transitions: Grade changes.” In *Preprints Reglermöte 2002*, pp. 370–375. Linköping, Sweden.

Åkesson, J. and K. J. Åström (2001): “Safe manual control of the Furuta pendulum.” In *Proceedings 2001 IEEE International Conference on Control Applications (CCA'01)*, pp. 890–895. Mexico City, Mexico.

Årzén, K.-E., R. Olsson, and J. Åkesson (2002): “Grafchart for procedural operator support tasks.” In *Proceedings of the 15th IFAC World Congress, Barcelona, Spain*.

Henriksson, D., A. Cervin, J. Åkesson, and K.-E. Årzén (2002a): “Feedback scheduling of model predictive controllers.” In *Proceedings of the 8th IEEE Real-Time and Embedded Technology and Applications Symposium*. San Jose, CA.

Henriksson, D., A. Cervin, J. Åkesson, and K.-E. Årzén (2002b): “On dynamic real-time scheduling of model predictive controllers.” In *Proceedings of the 41st IEEE Conference on Decision and Control*. Las Vegas, Nevada.