LINKÖPING UNIVERSITY
DIVISION OF AUTOMATIC CONTROL
ACTIVITY REPORT
2006

Contents

Chapter 1

Introduction

The Division of Automatic Control consists of some thirty persons. We teach thirteen undergraduate courses to more than a thousand students. The courses cover both traditional control topics and more recent topics in model building and signal processing.

During 2006 the Division hosted three international meetings: The third Swedish-Chinese Control meeting, the ERNSI (European Research Network for System Identification) workshop and the Symposium Forever Ljung in System Identification.

Anders Hansson was promoted to full Professor during the year and Alf Isaksson was appointed Adjunct Professor, sharing his time between ABB and our division.

Other highlights are that five PhD theses were defended: Markus Gerdin, Jonas Gillberg, Christina Grönwall, Ingela Lind and Thomas Schön all finished their doctoral degree during 2006. Moreover, Johan Sjöberg and David Törnqvist completed the Techn.Lic degrees.

The activities of the Strategic Research Centre MOVIII, funded by the Swedish Foundation for Strategic Research (SSF), were initiated during the year. This is a five year program.

A major EU-project, COFCLOU, which will deal with control strategies for aircraft was also granted during 2006. It will start in early 2007 with Anders Hansson as coordinator.

Research

Our research interests are focused on the following areas:

– *System Identification*: We are interested in a number of aspects ranging from industrial applications, to aspects of the fundamental theory and properties of algorithms.

– *Non-Linear and Hybrid Systems*: Here we are interested both in developing theory for nonlinear systems and to understand and utilise how modern computer algebraic tools can be used for practical analysis and design. Hybrid systems is an important and emerging field covering problems of how to deal with systems with both discrete and continuous phenomena.

– *Sensor Fusion*: Techniques to merge information from several sensors are of increasing importance. We are involved in four different industrial application of this kind, at the same time as we try to abstract the common underlying ideas. Particle filters play an important role in this context.

– *Diagnosis and Detection Problems* are very important in today's complex automated world. We work with several industrial problems of this kind.

– *Communication Applications*: We have several applied and theoretical projects that deal with communication systems.

– *Robotics Applications*: We have a close cooperation with ABB Automation Technology Products – Robotics, and several projects concern modelling and control of industrial robots.

– *Optimisation for Control and Signal Processing*: Convex optimisation techniques are becoming more and more important for various control and signal processing applications. We study some such applications, in particular in connection with model predictive control.

Details of these research areas are given in the corresponding sections of this report.

Funding

We thank the Swedish Research Council (VR), the Swedish Agency for Innovation Systems (VINNOVA/SEFS) and the Foundation for Strategic Research (SSF) for funding a major part of our research. A grant from SSF

funds a research program VISIMOD, which is a joint program for research in Visualisation, Modelling, System Identification, and Simulation. The participating groups are from the Departments of Electrical Engineering, Computer Science and from the Norrköping Visualisation and Interaction Studio, NVIS. The program leader of VISIMOD is Lennart Ljung. The center MOVIII, mentioned above is also funded by SSF.

Mover we have EU funding for participating in the European projects MATRIS and HYCON.

The Third Swedish-Chinese Control Meeting

The third Swedish-Chinese Control Meeting was organised in Linköping May 17-19. It follows the tradition of the first Stockholm meeting in 2003, and the second meeting in Beijing 2004, with a dozen speakers from each country in a concentrated but informal conference. The scientific program is included in Appendix H.

The ERNSI Workshop

The European Research Network on System Identification held its annual workshop in Linköping September 20 – 21. The program for this workshop is included in Appendix H, and some highlights are mentioned in Chapter 2.

The Forever Ljung Workshop

On the occasion of Lennart Ljung's 60th birthday, a Symposium with leading international researches was organised on September 22. I had about 100 participants, and further comments are given in Chapter 2. The program is included in Appendix H.

Undergraduate Education

As can be seen in Appendix B the Division of Automatic Control has extensive education activities with a large number of courses. The teaching staff of the division is also involved in education development and management of the engineering programs within Linköping University. One recent example of course development is presented in [20], which describes a student project carried out within the project course in Automatic Control. This course

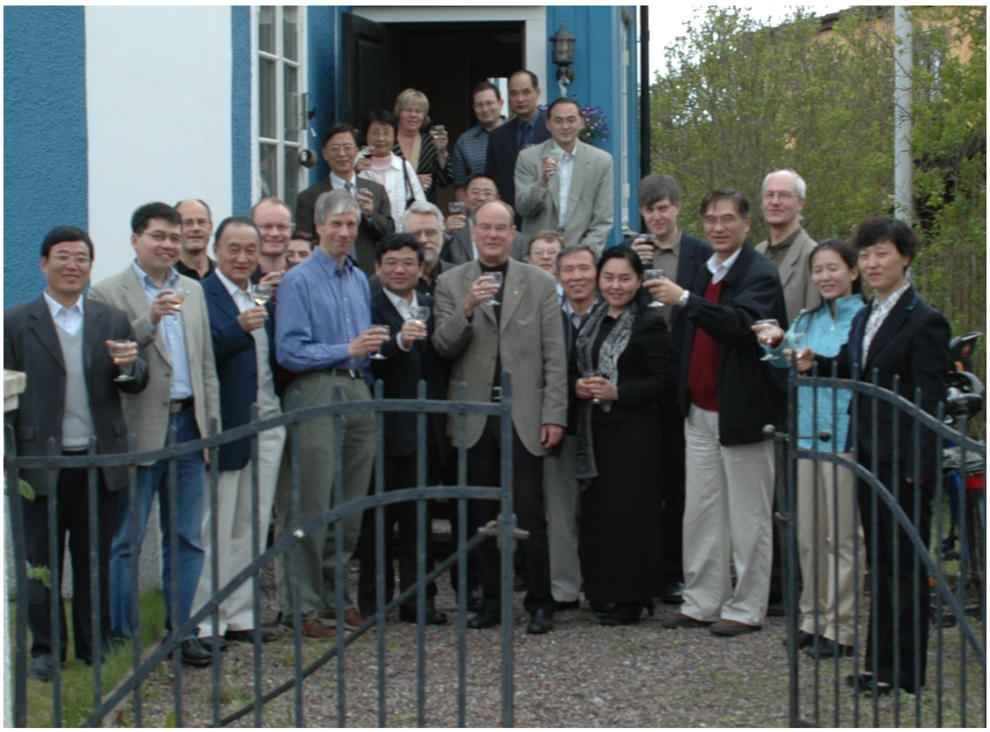

Figure 1.1: The participants of the Swedish – Chinese Control Meeting at the get-together party.

Figure 1.2: Swedish-Chinese Control Meeting: Reception at the local Governor's home at Linköping Castle).

Figure 1.3: The Banquet of the ERNSI Workshop was held at the Swedish Air Force Museum outside Linköping.

Figure 1.4: Rector Mille Millnert opens the Forever Ljung workshop.

Figure 1.5: A break during the workshop.

Figure 1.6: From the banquet: In the foreground Mille Millnert, Bia Åström and Jack Little.

has been redesigned during the last years as result of the participation of Linköping University in the so called CDIO Initiative. The collaboration within the CDIO Initiative has also resulted in cooperation and development on program level, as can be seen in [22] and [11].

Report Outline

In the following pages the main research results obtained during 2005 are summarised. More details about the results can be found in the list of articles and technical reports (See Appendices G and H. Numerals within brackets refer to the items of these appendices). These reports are available free of charge, most easily from our web-site. The next chapter describes how you can search for our publications in our data base and download any technical report.

Network Services

Mail addresses

There are a number of ways you can access the work produced at this group. Most convenient is probably to email the person you wish to contact. The email addresses are listed at the end of this activity report. Apart from these shorter but quite arbitrary email addresses you can always use the general form:

Firstname.Lastname@isy.liu.se

e.g., Lennart.Ljung@isy.liu.se.

We also have a generic email address:

Automatic.Control@isy.liu.se

or AC@isy.liu.se for short. Emails sent to this address are currently forwarded to our secretary Ulla Salaneck.

Finally, you can also retrieve reports and software electronically using our World Wide Web services. This is our preferred method of distributing reports.

World Wide Web

The most powerful way to get in touch with the group is probably by using our World Wide Web service (WWW). The address to our web pages is:

`http://www.control.isy.liu.se`

The VISIMOD Research Program is described in

`http://www.ida.liu.se/zope/portals/visimod`

and the Strategic Research Center MOVIII has the home page

`http://www.moviii.liu.se`

When you surf around in our WWW-environment you will find some general information over this group, the staff, seminars, information about undergraduate courses taught by the group and you have the opportunity to download technical reports produced at this group. This is the easiest way to access the group's work, just click and collect.

Our WWW service is always under development. We look forward to your feedback regarding this service. If you have any questions or comments, please send an email to our group of webmasters

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Chapter 2

System Identification

2.1 Introduction

Our research in System Identification covers a rather wide spectrum, from general principles to particular applications.

Several of the PhD-thesis completed during 2006 have some links to system identification. Three of them deal with central topics in identification: [2], [3] and [5]. These will be described in the next few sections.

2.2 Symposium Forever Ljung in System Identification

The symposium "Forever Ljung", mentioned in the introduction had a bias towards system identification. Leading international researchers contributed to the program:

- *Karl Johan Åström, Lund Institute of Technology, Sweden*: Adventures in System Identification.
- *Albert Benveniste, IRISA, Rennes, France*: The local approach to change detection, diagnosis, and model validation: Appliations to vibration mechanics.
- *Peter Caines, McGill University, Montreal, Canada*: Large population stochastic dynamic games: the Nash certainty equivalence principle and adaptation.

- *Michel Gevers, Université Catholique de Louvain, Belgium*: System Identification without Lennart Ljung: what would have been different?

- *Torkel Glad, Linköping University, Sweden*: Parameter identifiability from parameter-free equations – using model libraries.

- *Keith Glover, Cambrigde University, England*: Modelling IC engines: first principles, experiments and data analysis.

- *Graham Goodwin, Univerity of Newcastle, Australia*: Good, bad and optimal experiments for identification.

- *Lei Guo, Academy of Mathematics and Systems Science, Beijing, China*: On controllability of some classes of affine nonlinear systems.

- *Boris Polyak, Institute of Control Sciences, Moscow, Russia*: New challenges in nonlinear control: stabilization and synchronization of chaos.

- *Torsten Söderström, Uppsala University, Sweden*: Identifying charateristics of viscoelastic experiments from wave propagation experiments – Recent advances.

- *Bo Wahlberg, The Royal Institute of Technology, Stockholm, Sweden*: A control perspective on optimal input design in system identification.

The proceedings of the symposium were published by Studentlitteratur, [9]

2.3 The ERNSI Workshop

The European Research Network on System Identification (ERNSI, http://www.ernsi.org/) had its annual meeting Sept 21-22 in Linköping, hosted by the Automatic Control Division.

The plenary presentations were

- *Fredrik Gustafsson (Linköping)*: Vehicle Safety: Challenges in Sensor Fusion

- *Måns Ehrenberg (Uppsala)*: Intracellular pathways and control systems: Modeling and experimental verification of models

- *Alessandro Chiuso (Padova)*: Recent Development in Subspace Identification

The workshop had about 50 participants, several other oral presentations and a poster session.

2.4 Using ANOVA for Selecting Regressors in Non-linear Models

The PhD thesis of Ingela Lind, [5], studies the problem of regressor selection for nonlinear system identification. Regressor selection can be described as finding which regressors are important for constructing a good prediction model.

The approach taken in [5] is based on the classical ANOVA (analysis of variance) method. ANOVA selects regressors based on hypothesis tests (F-tests) at a certain confidence level that depends on data. The results of the F-tests also give information about whether the dependence of the regressor is in the form of a sum of univariate functions, one for each regressor, or if there is interaction between certain combinations of regressors. It is also shown in [5] how one can distinguish between linear and nonlinear dependencies of a regressor, by applying ANOVA to the residuals from a linear model fitted to the data. In a comparison of ANOVA to several other regressor selection methods, ANOVA gives better and more homogeneous results. For another comparison of regressor selection methods, see also [101].

As the number of candidate regressors grows, the amount of data needed to carry out a full ANOVA test becomes prohibitive. To this end, [5] proposes a systematic procedure called TILIA (test of interactions using layout for intermixed ANOVA), which applies ANOVA to a series of different subsets of the candidate regressors. TILIA has shown good performance on a variety of simulated and measured data sets.

In [5, 62, 61] it is shown that ANOVA can be viewed as an optimization problem, closely related to regularisation methods such as nn-garrote, Lasso, and wawelet shrinkage. Basically, one can view ANOVA as a two-step procedure, where in the first step a piecewise constant model with a special parameterization is fitted to data. Then, the second step is a regularization step, removing the terms of the model that do not significantly contribute to the predictions.

ANOVA in its original formulation assumes that the data set is balanced, i.e., that the data is evenly spread over the regressor space. The thesis [5] discusses the different aspects and effects of violating this assumption vs discarding data to obtain a more balanced data set.

2.5 Estimation of Continuous Time Models

The PhD thesis of Jonas Gillberg, [3], covers problems related to frequency-domain identification of continuous-time systems. Estimation of continuous-time models can be motivated by the fact that most modeling of physical systems takes place in the continuous-time domain. Identification based on both uniformly and non-uniformly sampled data is discussed in the thesis.

In identification of continuous-time systems with zero order hold inputs, it is interesting to consider the relation between a continuous-time model and the corresponding discrete-time model that describes the behavior of the system only at the sampling instants. This relation, which can be found in literature, can be used to parameterize a discrete-time model using the parameters of a continuous-time model. In principle, this enables direct identification of continuous-time systems from discrete-time data. However, since this exact approach often will be rather complicated, it is interesting to try approximate approaches.

Several approximate frequency-domain methods for direct estimation of continuous-time output-error models are presented and investigated in Jonas Gillberg's thesis. These methods are based either on approximate expressions for the relation between the continuous- and discrete-time models or on approximations of the continuous-time Fourier transform of the output signal. A common assumption is that the continuous-time model can be approximated with a number of integrators

$$\frac{b_0}{s^\ell}$$

at high frequencies. Furthermore, it is shown in the thesis that the approach based on an approximation of the continuous-time Fourier transform of the output can be used also with non-uniformly sampled data. In this case, the method involves interpolation of the signal samples using polynomial splines. These results are presented also in [35].

Identification of continuous-time autoregressive moving average (CARMA) models is also discussed in the thesis. These models can be used to describe a wide class of time series and it is shown that they can be estimated using the estimator

$$\hat{\theta} = \arg\min_{\theta} \sum_{k=1}^{N_\omega} \frac{\hat{\hat{\Phi}}_{c,T}(i\omega_k)}{\Phi_c(i\omega_k, \theta)} + \log \Phi_c(i\omega_k, \theta) \tag{2.1}$$

where $\Phi_c(i\omega, \theta)$ is the signal spectral density for a model with parameter vector θ and

$$\hat{\hat{\Phi}}_{c,T}(i\omega) = F^c_{2\ell,T_s}(i\omega)\hat{\hat{\Phi}}_{d,N_t}(i\omega)$$

is the continuous-time periodogram. Here, $F^c_{2\ell,T_s}(i\omega)$ is a weighting factor and

$$\hat{\hat{\Phi}}_{d,N_t}(i\omega)$$

is the standard discrete-time periodogram. The estimator (2.1) is a continuous-time counterpart to the discrete-time *Whittle likelihood estimator*. This approach is analyzed in detail and an extension to non-uniformly sampled data is presented. The relation between parameter bias and spectral density bias in a time series model is also described.

Furthermore, a method for the rejection of frequency domain outliers is proposed. This algorithm, which is based on previous results about *M-estimators* and the concept of *influence functions*, is derived for the purpose of frequency domain CARMA modeling, but it can be applied also to the discrete time case (see also [36]).

An real-life application in which a continuous-time auto-regressive model is estimated from non-uniformly sampled data is also presented in the thesis. This application concerns tire pressure estimation in cars and the idea is to estimate a time series model for the wheel speed signal. By tracking variations in a resonance peak in this model, it is possible to track changes in the tire pressure. The proposed method uses an interpolation-based approximation of the continuous-time Fourier transform of the wheel speed signal and the parameter estimate is obtained by a Whittle likelihood method.

2.6 Parameter Estimation in Differential-Algebraic Equations

Markus Gerdin's PhD thesis, [2] deals with parameter estimation in Differential-Algebraic Equations.

To make models of complex system, it is often desirable to combine physical modelling and system identification. This is called *grey box identification*. The classical approach to grey box identification has been to make state-space models with unknown parameters that are to be identified. However, modern modelling tools such as MODELICA are not based on state-space models. Instead the equations describing the system form a differential-algebraic equation (DAE),

$$F(\dot{\xi}(t), \xi(t), u(t), \theta) = 0. \tag{2.2}$$

Here $\xi(t)$ is a vector of physical variables, $u(t)$ is an input signal and θ is a vector of (possibly unknown) constant parameters. To be able to combine modern modelling tools with grey box identification, we examine how unknown variables θ in a DAE can be estimated from input and output data. The goal is that the user only should need to work with graphical models, such as the one in Figure 2.1. When the user has indicated which parameters that are unknown, where known inputs enter, where disturbances are present, and which signals that are measured and provided measurement data, the identification process should be fully automatic.

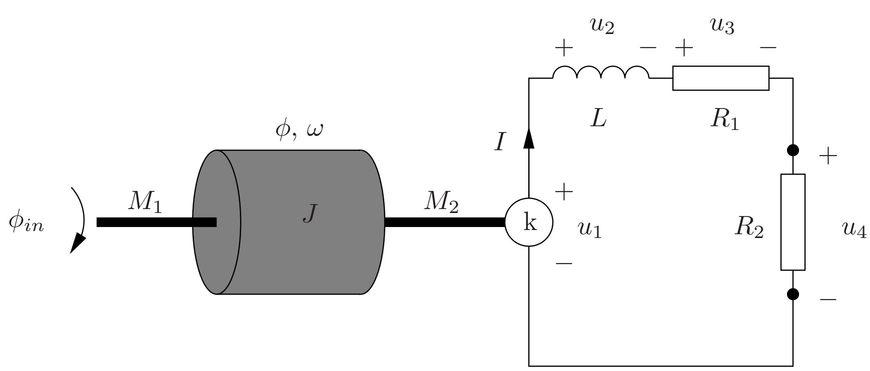

Figure 2.1: Modern modelling tools use graphical modelling. Research efforts are made to connect such modelling tools directly to identification software.

An important special case is when the DAE is linear,

$$E(\theta)\dot{\xi}(t) = J(\theta)\xi(t) + K(\theta)u(t) \tag{2.3a}$$

$$y(t) = L(\theta)\xi(t), \tag{2.3b}$$

Part II of [2] deals with this special case, and it discusses well-posedness and practical algorithms, as well as different transformations and canonical forms for the system (2.3). One important form is

$$\begin{bmatrix} I & 0 \\ 0 & N \end{bmatrix} \begin{bmatrix} \dot{z}_1(t) \\ \dot{z}_2(t) \end{bmatrix} = \begin{bmatrix} A & 0 \\ 0 & I \end{bmatrix} \begin{bmatrix} z_1(t) \\ z_2(t) \end{bmatrix} + \begin{bmatrix} B \\ D \end{bmatrix} u(t) \tag{2.4a}$$

$$y(t) = \begin{bmatrix} C_1 & C_2 \end{bmatrix} \begin{bmatrix} z_1(t) \\ z_2(t) \end{bmatrix} \tag{2.4b}$$

$$\xi(t) = Qz(t) \tag{2.4c}$$

where N is a nilpotent matrix and Q is an invertible matrix. One important characteristic of this form is that it can be computed efficiently using numerical software, which is important if it is going to be used in identification software.

The general nonlinear DEA case is discussed in part I of the thesis, and involves substantially more difficult questions. One is how to define and test identifiability. One approach is to rely upon the recent theory for observability of DAE-system by Kunkel and Mehrman. Another approach is to link the question to identifiabilty of polynomial DAEs, using differential algebra and Ritt's algorithm. In doing so, a method can be devised that brings back the question of global identifiabily to identifiability of (simple) subsystems and a signal identifiability property that can be phrased independently of the parameters. See also [33] and [37].

A third approach to identifiablity is discussed in the thesis and in [31]: To check if DAE solvers give unique solutions, if the parameters are treated as variables.

2.7 Nonlinear System Identification

Hammerstein Systems

A Hammerstein system consists of a static nonlinearity followed by a linear subsystem. This type of nonlinear system can be found in various applications, e.g., in control systems with saturating input signals. Because of this, identification of Hammerstein systems has been an active research field for many years. Several existing methods for solving this identification problem rely on initial estimation of approximate linear models. This approach can be motivated by the fact that the optimal linear approximation, in the mean-square error sense, of a Hammerstein system with a *separable* input signal is equal to the linear part of the system times a constant. A stochastic signal $u(t)$ is separable if

$$\mathrm{E}(u(t-\tau)|u(t)) = a(\tau)u(t),$$

where $a(\tau)$ is some function that does not depend on $u(t)$ and where E denotes expected value. For example, the class of separable signals contains Gaussian and white noise signals.

A popular class of input signals for identification purposes is *random multisines*. A random multisine signal is a signal that can be written

$$u(t) = \sum_{k=1}^{Q} A_k \cos(\omega_k t + \psi_k),$$

where ψ_k are independent random variables and A_k and ω_k are constants. In [30], it is shown that random multisines are separable if the phases ψ_k have uniform distribution on the interval $[0, 2\pi]$ and all amplitudes A_k are equal. Furthermore, it is shown that random multisines with these properties are particularly useful for identification of the linear parts of Hammerstein systems. Unlike most previous results about identification of Hammerstein systems using random multisines, the present separability result is independent of the number of frequency components (Q) in the signal. Most previous results are based on the fact that a random multisine has an asymptotic Gaussian distribution when the number of frequency components tends to infinity.

Some other properties of random multisine signals have also been investigated. For example, it has been shown that most random multisines contain distinctly non-Gaussian components that can be found by studying pairs of signal components. It turns out that the presence of these components depends on the ratio between the number of excited frequencies and the period length. It seems that random multisines with a high such ratio are more Gaussian-like than those with a low ratio and that results obtained under the assumption of an approximate Gaussian distribution thus should be more accurate.

In model-based robust control design, it is important to have not only a model of the system but also a measure of the size of the model errors. It is often hard to obtain an accurate description of the model errors, but upper bounds on the size of the errors are usually sufficient. In particular, if the $\mathcal{L}_2$ gain of the model error can be estimated, this information can be used for robust control design. Unfortunately, it is not obvious how the $\mathcal{L}_2$ gain of a general nonlinear model error can be estimated without first estimating a complex nonlinear model of these errors. Some possible approaches to gain estimation for Hammerstein systems are proposed in [26]. One approach is based on repeated experiments with modified input signals and resembles the power method from linear algebra. Using this method, a gain estimate can be obtained without first estimating a model. A second approach focuses on gain estimation for the unknown static nonlinearity in the Hammerstein system. This approach is based on resampling and requires that a model of the linear part of the system is estimated separately.

Structure Identification Using Linear Models

The selection of an appropriate model structure is often a critical step when identifying a nonlinear system. The model structure should be flexible enough to be able to capture the important system properties, but not too flexible. Hence, it can be useful to have methods for structure identification of nonlinear systems. An approach to structure identification that can be used for some classes of block-oriented systems has been developed together with people at the ELEC department at Vrije Universiteit Brussel in Belgium [55]. The underlying idea in this approach is to distinguish some types of system structures by considering linear models estimated from several specially designed experiments. The input signals used in these experiments differ either in their root mean square values or in their spectral densities, and these differences cause particular changes in the estimated linear models depending on the structure of the studied system.

Surveys

Two plenary and semiplenary presentations during the year concerned general aspects and issues in nonlinear system identification, [56], and [57]. The basic idea is to frame the problem in a curvefitting setting. Parametric and nonparametric approaches are singled out, and among parametric methods one can distinguish black, dark-gray and light-gray parameterisations, depending on the amount of physical insight employed.

An Approach to Identifying Wiener Models

A Wiener model is a nonlinear model consisting of a linear dynamical system , followed by a static nonlinearity. In [76] a new approach to identifying such systems is suggested. It is based on sorting the outputs assumeing that the static nonlinearity is monotonous, and then estimating the linear dynamics by quadratic programming. It works surprisingly well.

The Use of Particle Filters in Nonlinear identification

The paper [67] derives an Expectation Maximisation (EM) type algorithm for ML estimation of the parameters θ in the following model class

$$\begin{bmatrix} x_{t+1} \\ y_t \end{bmatrix} = \begin{bmatrix} f_1(x_t, u_t, t) \\ h_1(x_t, u_t, t) \end{bmatrix} \theta + \begin{bmatrix} f_2(x_t, u_t, t) \\ h_2(x_t, u_t, t) \end{bmatrix} + \begin{bmatrix} w_t \\ e_t \end{bmatrix}. \tag{2.5}$$

In devising this algorithm several conditional expectations have to be computed. Due to the nonlinearity in (2.5) there are no closed-form expressions available. Hence, an essential ingredient is the employment of a particle smoother to compute approximations of these conditional expectations.

2.8 Miscellaneous

Direct Weight Optimization

In earlier Annual reports, it has been described how a general nonlinear regression function can be estimated from data by a method we have termed Direct Weight Optimization (DWO). Given data $(y(t), \varphi(t))_{t=1}^N$ from a system

$$y(t) = f(\varphi(t)) + e(t)$$

the DWO method estimates $f(\varphi^*)$ for given regression vectors φ^* by minimizing an upper bound on the mean-square error. In [59], it is shown that the DWO method is optimal among all estimators for the case when f is the sum of a linear part and a bounded nonlinear part, and as long as the data does not lie too asymmetrically with respect to φ^*.

Hybrid Systems

Identification of piecewise affine systems has received some attention in recent years, and several different algorithms have been proposed. A piecewise affine autoregressive exogenous (PWARX) model can be written in the form

$$y(t) = \begin{pmatrix} \varphi^T(t) & 1 \end{pmatrix} \theta_i + e(t) \quad \text{if } \varphi(t) \in \mathcal{X}_i, \quad i = 1, \ldots, s$$

where $\varphi(t)$ is the regression vector and $\mathcal{X}_i$, $i = 1, \ldots, s$ is a polyhedral partition of the regressor space.

In a joint work with Aleksandar Juloski at Eindhoven University of Technology and Simone Paoletti at Università di Siena [18], four different algorithms for identification of PWARX models have been compared and evaluated from different aspects.

Software

An extended version of the MATLAB System Identification toolbox is getting close to finished. It covers both linear and nonlinear models in a comprehensive and coherent manner. It is described in [58] and will be released by the MathWorks in early 2007.

Robotics

Several projects on industrial robotics have dealt with identification and modelling issues. These are described in Section 7.2.

Aircraft

The papers [13] and [14] discuss parameter estimation of continuous-time polytopic models for a linear parameter varying (LPV) system. The prediction error method of linear time invariant (LTI) models is modified for polytopic models. The modified prediction error method is applied to an LPV aircraft system that has flight velocity as the varying parameter and stability and control derivatives (SCDs) as the model parameters. In an identification simulation, the polytopic model is more suitable for expressing the behaviors of the LPV aircraft system than the LTI model from the viewpoints of time and frequency responses. The SCDs of the initial polytopic model are adjusted to fit the model output to the output-data obtained from the LPV aircraft system.

Time- and Frequency Doman Methods

An ongoing discussion in system identification concerns the relationship between time domain and frequency domain methods, as decribed in several earlier annual reports. Several newer results have pointed to the kinship between the methods: they are essentially mirror images of each other with useful complemenatry properties. The paper [21] revisits this problem area, in the light of an older contribution.

Jitter

Reduced Rank Regression for Subspace Methods

Today, subspace-based state-space system identification is a standard estimation technique and several versions of it are available, e.g., MOESP, N4SID, IVM and CVA. This approach to state-space system identification rely on the estimation of the extended observability matrix of the system, or rather the n-dimensional signal subspace that it spans. Hence, it turns out that the minimization problem

$$\min_{\operatorname{rank}(F)=n} \det C(F), \tag{2.6}$$

where $C(F) = (Y - FX)(Y - FX)^T$, can be viewed as a key problem in state-space system identification. Here, Y and X are known matrices and the matrix to be determined, F, gives an estimate of the n-dimensional signal subspace spanned by the extended observability matrix. A generalized version of (2.6) is proposed in [23]. This generalized minimization problem can be written

$$\min_{F\in\mathcal{F}} \prod_{i=1}^{r_{\min}} \lambda_i(C(F)), \tag{2.7}$$

where $\lambda_i(C(F))$, $i = 1, \ldots, r_{\min}$ denote the eigenvalues of $C(F)$ in decreasing order,

$$r_{\min} = \min_{\operatorname{rank}(F)=n} \operatorname{rank}(C(F))$$

and

$$\mathcal{F} = \{F : \operatorname{rank}(F) = n \text{ and } \operatorname{rank}(C(F)) = r_{\min}\}.$$

The problem (2.7), which can be viewed as a volume minimization problem, is equivalent to (2.6) when $C(F)$ has full rank for all F. However, (2.7) can be used also in cases where the original problem will not produce any useful solution. Both the original and the generalized problem are analyzed in detail in [23] and the applicability of the proposed method to subspace-based state-space system identification is illustrated in numerical examples.

Chapter 3

DAE models

DAE (differential algebraic equations) models contain a mixture of differential and static (“algebraic”) relations. In most cases they can in principle be rewritten in state space form. However, the dimension of the state space and the choice of state variables is often not obvious from the beginning. Also it might not be possible to represent the state space form explicitly even if it is known (from the omplicit function theorem) to exist.

3.1 Structure of models

A fairly general DAE model might have the structure

$$F(\dot{x}, x, u) = 0$$

where x is a vector of physical variables and u is the input. In many cases F is a multivariable polynomial in its variables. In that case the mathematical theory of differential algebra is a powerful tool for analysis and manipulation of the model. In [38] it is shown how the structure of the DAE model and in particular the separation into state space description and static relationships can be analyzed using differential algebra.

3.2 Well-posedness of models

Differential-algebraic equation models naturally arise when modeling physical systems from first principles. To be able to use such models for state estimation procedures such as particle filtering, it is desirable to include a noise model. In [34] the well-posedness of differential-algebraic equations with noise models is discussed. Since the exact conditions are rather involved, approximate implementation methods are also discussed. It is also discussed how a particle filter can be implemented for DAE models, and how the approximate implementation methods can be used for particle filtering. Finally, the particle filtering methods are exemplified by implementation of a particle filter for a DAE model.

3.3 Identification

The identification of DAE models requires several extensions of the methods developed for state space and input-output models. In [2] a systematic treatment of identification of both linear and nonlinear DAE models is developed.

A basic question is identifiability, i.e. whether it is at all possible to determine the parameters of a DAE model from measurements. Since DAE models are often obtained by connecting simple models from model libraries, the identifiability of such models is of particular importance. In [33] and [37] it is shown how identifiability criteria for such models can be obtained in an algorithmic fashion.

Observability is a property related to identifiability which is important in applications such as control and diagnosis. In [31], recent results on analysis of nonlinear differential-algebraic equations are used to derive new proofs for classical criteria for local identifiability and local weak observability for DAE models. The criteria are based on rank tests.

The development of reliable numerical software for simulation of DAE models gives new possibilities to test identifiability numerically. Several such methods are presented in [32].

3.4 Optimal Control

When extending optimal control methods to DAE models there are two ways to go. One is to reduce the problem to a state space problem and then use traditional optijmal control theory. The other approach formulates the Hamilton-Jacobi equation directly for the descriptor system. In [39] the two approaches are shown to give essentially the same systems of equations to be solved (as expected). A certain unknown function present only in the second approach is shown to be computable from the quantities common to both approches.

The equations describing the necessary conditions are fusually not solvable explicitly. In [70] power series solutions for nonlinear time-varying optimal control problems are developed. It is shown that they possess a well-defined feedback solution in a neighborhood of the origin. Explicit formulas for the series expansions of the cost function and control law are given.

An analysis of several methods for extending optimal contorl methods to DAE models is given in [7].

3.5 Controllability and Observability

For linear, possibly time-varying systems, controllability and observability can be characterized by the appropriate Gramians. For nonlinear systems in state space form the corresponding calculations lead natually to optimal control formulations. These methods can in turn be extended to DAE models, which is considered in [68]. There three different methods are derived. The first method is based on the necessary conditions for optimality from the Hamilton-Jacobi-Bellman theory for descriptor systems. The second method uses completion of squares to find the solution. The third method gives a series expansion solution, which with a finite number of terms can serve as an approximate solution.

Chapter 4

Sensor fusion

4.1 Main events

Highlights of the year are

- The doctoral thesis of Thomas Schön [6] and Christina Grönwall [4].
- The plenary presentations [42, 43].

4.2 Project overview

- **Particle filtering.** The theoretical research focuses on obtaining scalable and real-time algorithms for sensor fusion applications, where marginalization is the key tool, see [66, 65, 44].
  Fundings: Swedish Research Council (VR).
- **Sensor fusion applications.** The vision and mission are to position everything that moves. We have applications to aircraft, cars (see next area below), surface ships, underwater vessels, film cameras, cellular phones and industrial robots. One leading theme is to consider cameras and Geographical Information Systems (GIS) as standard sensors in sensor fusion. A technical driver is to backup, support or replace GPS in critical integrated navigation systems. In some cases, the (Extended) Kalman filter is used in our application, but in particular when GIS are used, the particle filter and marginalized particle filter mentioned

above are applied.
Fundings:

- Swedish Research Council (VR).
- MOVIII (SSF)
- Marker-less augmented reality Matris (EU FP5) (positioning film cameras).
- NFFP: Sense and avoid of aircraft.
- Linklab: navigation of UAV's.
- ARCUS (TAIS): navigation of UAV's.
- FOCUS (Vinnova institute centre): sensor networks
- FOI: Department for laser systems (positioning ground targets).

- **Sensor fusion for automotive safety systems** is a central activity at the sensor fusion group, see the survey [42].
Fundings: Two IVSS (Intelligent Vehicle Safety Systems) projects:

  - Systems for Collision Avoidance
  - Sensor Fusion Systems (SEFS)
  - Long-term collaboration with Volvo Car and Nira Dynamics AB.

- **Sensor networks.** The research concerns localization in sensor networks, and fundamental limitations with particular focus sensor units equipped with microphones, magnetometers, geometers.

4.3 Sensor fusion projects

The current projects include

- Our contributions to the marginalized particle filter is thoroughly overviewed in [66, 65, 44]. As a general tool, it has the potential of increasing estimation accuracy and reducing computational complexity at the same time.

- Fundamental limitations in filtering. What is the ultimate accuracy that can be achieved given infinite computational and memory resources? The Cramér-Rao lower bound gives once such accuracy bound for the second order moment. For linear systems with non-Gaussian noise, the Kalman filter is the linear filter that provides the best second order accuracy, but non-linear filters as the particle filter may give much better performance. In [93], explicit results are given for this case.

- Underwater and surface navigation using terrain databases is presented in the TSP paper [19]. The contribution here is a dedicated analysis and algorithm, with intuitive Cramer-Rao bound expressions for how good the performance might be.

- Track before detect is a concept for sensor-near signal processing of radar signals. The idea is to fuse the information on the returned radar signal, and not to apply threshold detection as is done in conventional radar system. In this way, an extended target model that also includes the target's spatial size is tracked, with potential benefits for association and classification applications for instance. Our work in [12] has a length state of each tracked aircraft.

- Particle filters for differential algebraic equations pose a quite specific problem as described in the theses [6, 2]. Basically, DAE:s appear from physical modeling, and in this context no process noise is usually included. However, for filtering by for instance the particle filter, certain process noise is needed for model errors, actuator noise and roughening of the filter. What is specific with DAE:s is that noise in certain subspaces correspond to non-causality, and the contribution is a contrutive way to determine in what subspace the state noise may reside.

- Object classification based on laser radar imaging systems is presented in the TIP paper [16] and thesis [4].

4.4 Automotive collision avoidance

An automotive collision avoidance system incorporates many important sensor fusion aspects:

- Navigation for ego-motion estimation.
- Target tracking for situational awareness.
- Road prediction for hazard evaluation.
- Decision support.

The challenge is to design these in a system showing an extremely low false alarm rate and good intervention performance. Our collaboration with Volvo Car Corp has given valuable knowledge, which has been substantiated in several demonstrator vehicles that have been tested extensively with successful result. The publications this year include the following ones: [42] [63] [64] [41] [27]

- A sensor fusion framework for all three tasks of navigation, tracking and road prediction. This includes a curved coordinate system following the road [63, 64], where the host vehicle's and tracked vehicles' lateral positions are given as deviations from the reference lane. In this way, all relevant parameters are collected in one state vector, where sensor inputs from own intertial sensors and wheel speeds are mixed with radar, lidar, IR and vision information in a common measurement model.
- For off-line analysis, the on-line filter estimates have to be validated against ground truth, which is often difficult to find. For instance, road curvature is only roughly given by digital maps. The idea in [27] is to apply smoothing to the vision measurements of the road marks, which have proven to provide a fairly accurate value of road curvature.
- A Monte Carlo approach to threat assessment is presented in [28].

4.5 Estimation in nonlinear dynamic systems

Thomas Schön's thesis [6] deals with estimation of states and parameters in nonlinear and non-Gaussian dynamic systems. Sequential Monte Carlo methods are mainly used to this end. These methods rely on models of the underlying system, motivating some developments of the model concept. One of the main reasons for the interest in nonlinear estimation is that problems of this kind arise naturally in many important applications. Several applications of nonlinear estimation are studied.

The models most commonly used for estimation are based on stochastic difference equations, i.e., state-space models. This thesis is mainly concerned with models of this kind. However, there is also a brief digression from this, in the treatment of the mathematically more intricate differential-algebraic equations. Here, the purpose is to write these equations in a form suitable for statistical signal processing.

The nonlinear state estimation problem is addressed using sequential Monte Carlo methods, commonly referred to as particle methods. When there is a linear sub-structure inherent in the underlying model, this can be exploited by the powerful combination of the particle filter and the Kalman filter, presented by the marginalized particle filter. During the year we have been invited to deliver plenary and semi-plenary lectures on the topic, see [65, 44]. This algorithm is also known as the Rao-Blackwellized particle filter and it is thoroughly derived and explained in conjunction with a rather general class of mixed linear/nonlinear state-space models. Models of this type are often used in studying positioning and target tracking applications. This is illustrated using several examples from the automotive and the aircraft industry [65]. Furthermore, the computational complexity of the marginalized particle filter is analyzed.

The parameter estimation problem is addressed for a relatively general class of mixed linear/nonlinear state-space models. The expectation maximization algorithm is used to calculate parameter estimates from batch data [67]. In devising this algorithm, the need to solve a nonlinear smoothing problem arises, which is handled using a particle smoother. The use of the marginalized particle filter for recursive parameter estimation is also investigated.

The applications considered are the camera positioning problem arising from augmented reality and sensor fusion problems originating from automotive active safety systems. The use of vision measurements in the estimation problem is central to both applications. In augmented reality, the estimates of the camera's position and orientation are imperative in the process of overlaying computer generated objects in a live video stream, see Figure 4.1 for the prototype used when conducting this research [52]. The objective in the sensor fusion problems arising in automotive safety systems is to provide information about the host vehicle and its surroundings, such as the position of other vehicles and the road geometry. Information of this kind is crucial

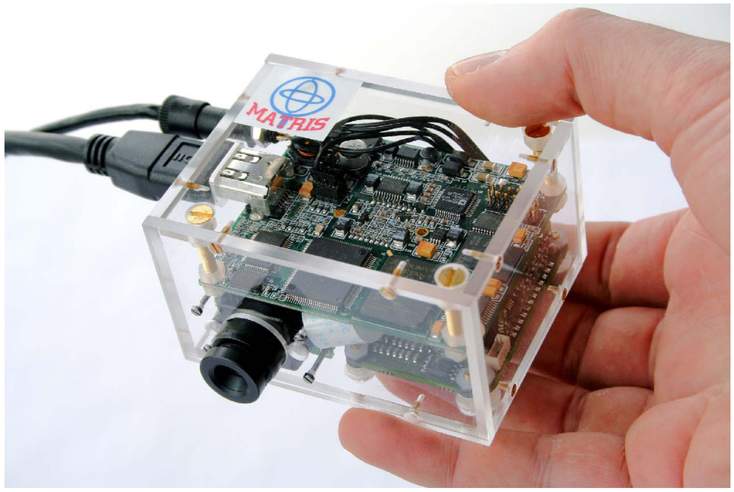

Figure 4.1: This is a prototype developed in the MATRIS project. It consists of a camera, an IMU and a low-power digital signal processor, used for preprocessing of the sensor signals. Courtesy of Xsens Technologies B.V.

for many systems, such as adaptive cruise control, collision avoidance and lane guidance [63].

4.6 Laser radar systems

This project concerns target recognition methods and performance analysis of estimation algorithms based on data from a generic laser radar system. This year's work treated recognition of ground targets with complex shape. The results of this long-term project is reported in the IEEE TIP paper [16] and thesis [4].

Data processing methods in this area are usually developed separately for military or topographic applications, seldom with both application areas in mind. In civilian applications, ground surface estimation and classification of natural objects, for example trees, is common. Once the natural objects have been detected and classified, buildings can be reconstructed and vehicles can be recognized. An overview of methods from both areas is presented. By combining methods originating from civilian and military applications, we believe that the tools for scene analysis becomes available.

The approach to recognition of ground targets is based on irregularly sampled laser radar data. The method is based on the fact that man-made objects of complex shape can be decomposed to a set of rectangles. The ground target recognition method consists of four steps; estimation of the target's 3D size and orientation, segmentation of the target into parts of approximately rectangular shape, identification of segments that contain the main parts of the target and matching the of target with CAD models. An example is shown in Figure 4.2. Its application in a decision support system for ground target recognition is also described.

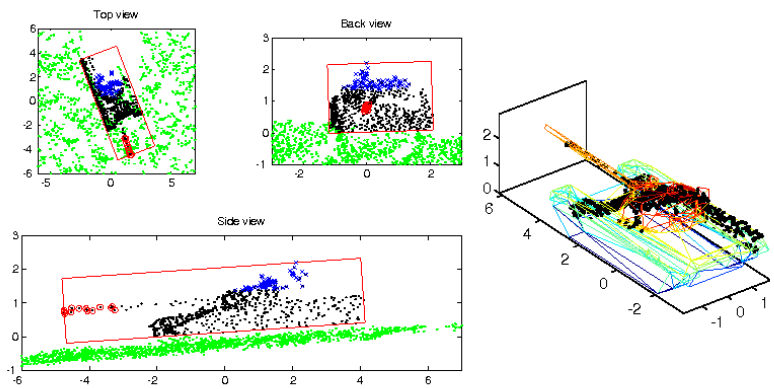

Figure 4.2: Target recognition of a tank. Left: 3D size and orientation estimation using rectangle fitting. The identified main parts are barrel (o) and turret (x). Right: Matching with low-resolution CAD model.

Chapter 5

Detection and Diagnosis

The problem of detecting faults in an environment where the measurements are affected by additive noise is considered here. To do this, a residual sensitive to faults is derived and statistical methods are used to distinguish faults from noise. Standard methods for fault detection compare a batch of data with a model of the system using the *generalized likelihood ratio*. Careful treatment of the initial state of the model is quite important, in particular for short batch sizes. One method to handle this is the parity-space method which solves the problem by removing the influence of the initial state using a projection.

The parity space approach to fault detection and isolation (FDI) has been developed during the last twenty years, and in [43] the focus is to describe its application to stochastic systems. A mixed model with both stochastic inputs and deterministic disturbances and faults is formulated over a sliding window. Algorithms for detecting and isolating faults on-line and analyzing the probability for correct and incorrect decisions off-line are provided. A major part of the paper is devoted to discussing properties of this model-based approach and generalizations to cases of incomplete model knowledge, and non-linear non-Gaussian models. For this purpose, a simulation example is used throughout the paper for numerical illustrations, and real-life applications for motivations. The final section discusses the reverse problem: fault detection approaches to statistical signal processing. It is motivated by three applications that a simple CUSUM detector in feedback loop with an adaptive filter can mitigate the inherent trade-off between estimation accuracy and tracking speed in linear filters.

In [8] the case where prior knowledge about the initial state is available is treated. This can be obtained for example from a *Kalman filter*. Combining the prior estimate with a minimum variance estimate from the data batch results in a smoothed estimate. The influence of the estimated initial state is then removed. It is also shown that removing the influence of the initial state by an estimate from the data batch will result in the parity-space method. To model slowly changing faults, an efficient parametrisation using Chebyshev polynomials is given.

The methods described above have been applied to an *Inertial Measurement Unit*, IMU [8]. The IMU usually consists of accelerometers and gyroscopes, but has in this work been extended with a magnetometer. Traditionally, the IMU has been used to estimate position and orientation of airplanes, missiles etc. Recently, the size and cost has decreased making it possible to use IMU:s for applications such as augmented reality and body motion analysis. Since a magnetometer is very sensitive to disturbances from metal, such disturbances have to be detected. Detection of the disturbances makes compensation possible. Another topic covered is the fundamental question of observability for fault inputs. Given a fixed or linearly growing fault, conditions for observability are given.

The measurements from the IMU show that the noise distribution of the sensors can be well approximated with white Gaussian noise. This gives good correspondence between practical and theoretical results when the sensor is kept at rest. The disturbances for the IMU can be approximated using smooth functions with respect to time. Low rank parametrisation can therefore be used to describe the disturbances. The results show that the use of smoothing to obtain the initial state estimate and parameterisations of the disturbances improves the detection performance drastically.

A new idea of anti-causal Kalman filtering in the present data batch is introduced and compared to the standard approaches: parity space, where the influence of the initial state is removed by projection, and the other one is using prior information obtained by Kalman filtering past data[71, 72, 105]. An efficient parametrization of incipient faults is given. It is shown in simulations of torque disturbances on a DC-motor that efficient fault profile parametrization and using smoothed estimates of the initial state increase performance considerably.

Sophisticated fault detection (FD) algorithms often include nonlinear mappings of observed data to fault decisions, and the performance of these nonlinear fault detection schemes is hard to decide objectively. Therefor Monte Carlo simulations are often used to get a subjective measure and relative performance for comparing different algorithms. There is a strong need for a constructive way of computing an analytical performance bound, similar to the Cramér-Rao lower bound for estimation. In [47] such a result for linear non-Gaussian systems is provided. It is first shown how a batch of data from a linear statespace model with additive faults and non-Gaussian noise can be transformed to a residual described by a general linear non-Gaussian model. This also involves a parametric description of incipient faults. The generalized likelihood ratio test is then used as the asymptotic performance bound. The test statistic itself may be impossible to compute without resorting to numerical algorithms, but the detection performance scales analytically with a constant that depends only on the distribution of the noise. It is described how to compute this constant, and a simulation study illustrates the results.

Chapter 6

Communication Applications

6.1 Introduction

In the third generation cellular radio systems, the available resource is not fixed, but flexible and depend critically on the network deployment. The wireless communication system comprises many algorithms which have to be implemented in a distributed fashion but mutually affect each other. Also the information is distributed, and full observability of the system behavior is almost always not possible. Therefore, careful design and analysis of the various algorithms is crucial.

The communication applications projects are carried out in cooperation with Ericsson Research. The aim is to apply methods from control theory and signal processing to algorithms on different layers in wireless communications systems.

6.2 Radio Resource Management

A prerequisite for proper behavior of radio network algorithms is that not more users than actually can be served are admitted into the system. This is of course intuitive, but with limited observability rather difficult to ensure. The situation is especially hard in the uplink communications from mobiles to the base stations, since the system has no absolute control of the transmitter powers p_i of the mobiles. These depend in turn on the radio propagation conditions from mobile i to base station j, g_{ij}, which are subject to rapid changes, and the received radio signal quality in terms of *carrier-to-*

total-interferece-ratio (CTIR) β_i. Each mobile contribute $Ci, *$ to the total received power both to the set of connected base stations K_i, which can control the mobile to some extent, and to all other base stations, which cannot control the mobile. This is illustrated by Figure 6.1. A common measure

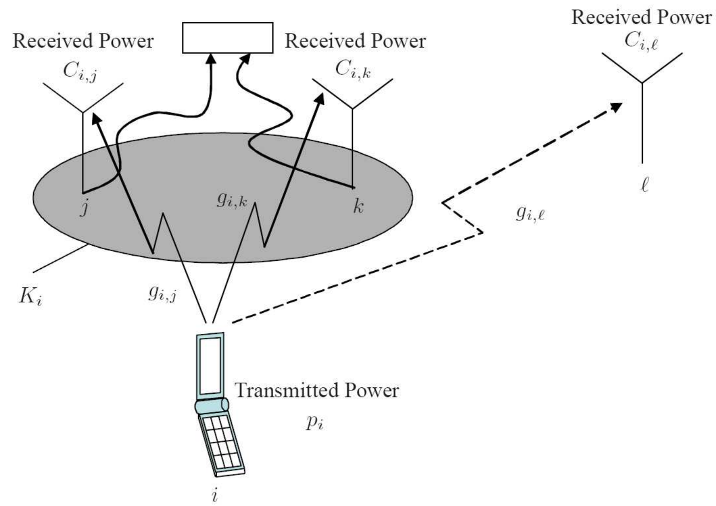

Figure 6.1: Radio access network with a mobile connected to an active set of base stations, and contribution to the interference in all base stations.

of the uplink load is the noise rise Λ_j, which is the ratio between the total received power $I_j^{tot} = \sum_i C_{i,j} + N_j$ and the backround noise N_j. Furthermore since the connections mutually affect each other, it is important there exists a power allocation that supports the requirements of all users in terms of β_i, i.e. that the power control problem is *feasible*.

Several authors have stressed the soft capacity property of CDMA systems, where the capacity depend on the radio conditions of the connections, in contrast to hard capacity, where the amount of resources are fixed. Furthermore, it is instructive to discuss the soft capacity in terms of the relative load, i.e. relative a max capacity. The research is based on two different relative load measures:

- *Noise rise relative load* L_j^{nr} based on the pole equation

$$\Lambda_j = \frac{1}{1 - L_j^{nr}}$$

- *Feasibility relative load* L_j^f is based on the feasibility property of the power control problem, and it describes the relation between the current load and the load at which the power control problem becomes infeasible.

Since the connections mutually affect each other, the relations between noise rise, CTIR and radio conditions are non-linear, approximations and fix-point iterations are employed to estimate noise rise. The properties of the approximations are analyzed, and it is proved that they serve as tight bounds for the noise rise relative load and the feasibility relative load. Furthermore, point iterations of approximations converge given a feasible system, and the convergence point is the noise rise relative load under certain conditions [15].

The step from the uplink load properties described above, to uplink load control is natural. The main challenge is limited information. Either the control algorithm is hosted in a central node and then receives limited information from a wide area. Or, the algorithm is located in a local node (base station) and then has only good knowledge of the situation in the corresponding cell. The proposed suite of load control algorithms uses decisions made both in a central node and in the base stations. The central node, operating on a slow update rate, guarantees system stability and controls the resource pool to provide resource usage restrictions to the base stations. In addition, the base stations can make fast decisions to improve performance based on rapid changes in the local radio environment, while followin the resource restrictions from the central node. In detail, the central node uses a utility function to handle the trade-off between maximizing the total resources and providin fairness, and the solution to the convex optimization problem gives constraints distributed to the base station, which in optmizes the resource allocation between connected users. This is illustrated by Figure 6.2

Related is also the work on more advanced base station receivers. Uplink interference cancellation is considered as a means to handle highly loaded base station. The optimal solution to the multiuser detection problem is intractable in practice. Instead, various suboptimal solutions are discussed. One approach is to formulate multiuser detection as a maximum likelihood problem, which leads to a binary quadratic programming problem. The pseudo-random sequences used in CDMA gives low correlation between two different connections. This fact can be exploited in a preprocessing algorithm, which is capable of detecting most users, and significantly reducing the complexity.

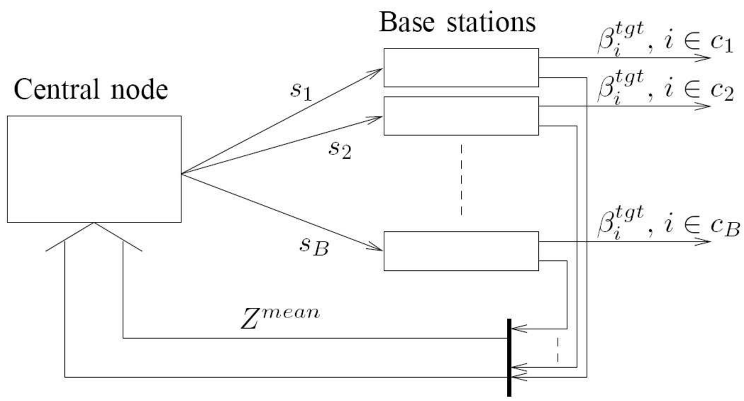

Figure 6.2: Schematic view of decentralized RRM with centralized coordination based on limited feedback Z^{mean} and resource pool signaling s_i from the central node to the base stations.

The long term evolution (LTE) of 3G will introduce a new radio interface based on Orthogonal Frequency Division Multiple Access (OFDMA) instead of Code Division Multiple Access (CDMA). This means that the radio resources are divided into resource blocks in both time and frequency. This means that traditions from second generation time-frequency division systems applies again. As before, load control is to a large extent about inter-cell interference coordination (ICIC). Some methods for downlink ICIC are investigated in the Master Thesis [123].

6.3 Related Work

Some work bridges the reasearch projects. Positioning in wireless communication networks is one example where a sensor fusion approach is used to address the problem. Since nonlinearities and non-Gaussian noise are present, the particle filtering framework is plausible.

Chapter 7

Robotics

7.1 Introduction

The research within the robotics area is to a large extent carried out in cooperation with ABB Robotics. The collaboration with ABB is a result of the competence center ISIS (Information Systems for Industrial Control and Supervision) which was supported by VINNOVA until 2005. The research during 2006 was mainly supported by the Swedish Research Council (VR). The overall aim of the work is to study and develop methods for improvement of the performance of robot control systems.

7.2 Identification of Industrial Robots

An industrial robot represents a challenging task for system identification since it is a multivariable, nonlinear system operating in closed loop. One sub-problem is to identify physically parameterized models at joint level, including the motor and the gear box. Such models have to include several nonlinear phenomena, such as nonlinear stiffness of the mechanical flexibility and nonlinear friction. One approach to this problem is suggested in [74], where both nonlinear friction and nonlinear stiffness is considered. The approach is based on a three step procedure, where the first two steps are used to determine suitable initial values of the parameters in a gray-box model. In the third step the parameter estimates are further refined using an iterative prediction error minimization. In [74] the method is applied to experimental data from a large size industrial robot with good results. The three-step procedure is also utilized [40] for identification of a parallel robot structure. Grey-box identification is also studied in [120], but in this case in a recursive formulation.

An indirect form of gray-box identification is considered in [60], which deals with the problem of identifying the spring stiffness coefficients of a six degrees-of-freedom robot by fitting a parameterized model to an estimate of the multivariable frequency response function (MFRF).

7.3 Iterative Learning Control

A common application of industrial robots is to repeat the same series of events over and over again. The *Iterative Learning Control (ILC)* method is a way to compensate for a repetitive error when the same task is performed repeatedly. At every iteration the system starts from the same initial conditions and knowledge from previous iterations is used in order to reduce the error in the next iteration. The idea of using an iterative method to compensate for a repetitive error has been studied for some decades. When letting a machine do the same task repeatedly it is, at least from an engineering point of view, very sound to use knowledge from previous iterations of the same task to try to reduce the error next time the task is performed.

The structure of the problem is shown in Figure 7.1 where the output of the ILC algorithm is $u_{k+1}(t)$ defined for $0 \leq t \leq t_f$.

Mathematically the algorithm can be formulated as

$$u_{k+1} = Q(u_k + Le_k)$$

where u_k is the input to the controlled system and e_k is a measure of the

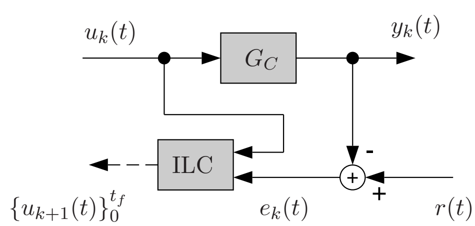

Figure 7.1: An example of a system controlled using ILC.

control error. Q and L are operators that can be chosen by the user. In [107] a heuristic design methodology for the filters Q and L is evaluated on a large industrial robot. It is shown that the error decreases and reaches a steady-state level after approximately 4 iterations. To test the robustness of the algorithm the same circular motion is performed by the robot in three different positions and at different path velocities. By changing Q and L it is also shown in the experiments how the convergence speed and resulting errors change, and the results validate the theoretical results shown in previous publications. An extension to the ILC algorithm above is the high order ILC,

$$u_{k+1} = H_{u_1} u_k + \ldots + H_{u_N} u_{k-N+1} + H_{e_1} e_k + \ldots + H_{e_N} e_{k-N+1}$$

where the control inputs and the errors from more than the previous iteration are included in the update equation. In [17] disturbance properties of high order iterative learning control (ILC) algorithms are considered. An error equation is formulated, and using statistical models of the load and measurement disturbances an equation for the covariance matrix of the control error vector is derived. The results are exemplified by analytic derivation of the covariance matrix for a second order ILC algorithm.

7.4 Sensor integration

Modern industrial robot control is usually based only upon measurements from the motor angles of the manipulator. The ultimate goal however is to make the tool move according to some predefined path and this is achieved by using a model of the robot and compute the torques and position references that should give a perfect tracking of the tool trajectory. By including measurements from the actual motion of the arm, using sensor integration, it is possible to increase the tracking accuracy and in previous work a tool mounted accelerometer has been considered.

To be able to incorporate the information from an extra sensor, such as an accelerometer, it is necessary to have a model of the robot where the measurements $y(t)$ can be calculated from the states $x(t)$ and the system input $u(t)$,

$$\dot{x}(t) = f(x(t), u(t))$$
$$y(t) = h(x(t), u(t))$$

In [73] a first step toward making a toolbox in Maple for modeling the robot kinematics, the function $h(\cdot)$, is taken. Position and orientation of the tool can be determined in terms of the Denavit-Hartenberg joint variables and also the Jacobian relating the linear and angular velocities to the joint velocities. It is also possible to find expressions for the linear acceleration by including a differentiated Jacobian. Future work includes to evaluate different kinds of sensors and sensor locations and symbolically generate the kinematic models using Maple. It also means to incorporate the models in Matlab- or C-code for including the results in, for example, an Extended Kalman Filter algorithm for state estimation.

An example of sensor integration for control is also presented in [127], where accelerometer feedback is used to improve the disturbance rejection properties of a large size industrial robot.

Chapter 8

Optimization for Control and Signal Processing

8.1 Introduction

The research in optimization for control and signal processing is currently focused on efficient optimization algorithms for robustness and stability analysis of control systems, for model predictive control and for model reduction.

8.2 Optimization Algorithms for Robustness Analysis

In this project we study how to construct efficient Interior-Point (IP) algorithms for the Semidefinite Programs (SDPs) that originate from the Kalman-Yakubovich-Popov (KYP) lemma. They have several applications, e.g., linear system design and analysis, robust control analysis using integral quadratic constraints, quadratic Lyapunov function search, and filter design.

Typically standard SDP solvers cannot handle KYP-SDPs of more than small to medium size in reasonable time, typically the limit is about 50 state-variables, resulting in roughly 1000 optimization variables. With specially tailored KYP-SDP-solvers problems with several hundred state-variables, corresponding to roughly tenths of thousands of variables can be handled.

The computational complexity stems from the cost of assembling and solving the equations for the search directions in the IP algorithms. Two avenues have been investigated to circumvent this problem. One is to instead of IP algorithms use decomposition algorithms. This work has been presented in [109].

Another way of attacking the above problem is to consider the dual problem and make use of an image representation of some of the constraints. This will reduce the number of variables in the dual problem such that the computation complexity for IP mehtods is reduced with two orders of magnitude with respect to the state-dimension. In case a state transformation is performed sparsity and low-rank structure can be further exploited such that the computation complexity is reduced with another order of magnitude. A Matlab implementation of the algorithm is publically available at `http://www.control.isy.liu.se/research/authors/reports/2517/kypd.html` and is described in more detail [45, 91]. The solver is one of the solvers in YALMIP.

8.3 Model Predictive Control

Model Predictive Control (MPC) has proven to be very useful in process control applications. Efficient optimization routines to be used on-line is an active area of research. In recent years the interest in controlling so-called hybrid dynamical systems has increased. Hybrid dynamical systems are systems with both continuous and discrete components. They are useful, e.g., when modeling systems containing logics, binary control signals or when approximating non-linear systems as piecewise linear systems. When MPC is used for control of hybrid systems, the optimization problem to solve at each sampling instant becomes a Mixed Integer Quadratic Programming (MIQP) problem. These problems have in general exponential computational complexity in the number of discrete variables and are known to be $\mathcal{NP}$-hard. In order to be able to solve such optimization problems in real time, it is necessary to decrease the computational effort needed. Research has been done on utilizing structure when solving these MIQP problems. The results are presented in [25, 24].

8.4 Model Reduction

Model reduction is an important toll when modeling dynamical systems and designing controllers. In this work we consider model reduction of LTI systems using Linear Matrix Inequalities in an H_∞ framework, where non-convex constraints are replaced with stricter convex constraints thus making it sub-optimal but easier to compute. The resulting algorithms have been compared with the Optimal Hankel reduction algorithm, and have been shown to achieve better results (i.e lower H-infinity errors) in cases where some of the Hankel singular values are close, but not equal to each other. The results are presented in [80].

Appendix A

Personnel

Lennart Ljung is Professor and head of the control group since 1976. He was born in 1946 and received his Ph. D. in Automatic Control from Lund Institute of Technology in 1974. He is a member of the Royal Swedish Academy of Engineering Sciences (IVA) and the Royal Swedish Academy of Sciences (KVA). He is an honorary member of the Hungarian Academy of Engineering, and a Foreign Associate of the US National Academy of Engineering (NAE). He is also an IEEE Fellow and an IFAC Advisor, and associate editor of several journals. He has received honorary doctor's degrees from the Baltic State Technical University in S:t Petersburg, Russia (1996), from Uppsala University, Uppsala, Sweden (1998), from l'Université de Technologie de Troyes, France (2004) and from the Katholieke Universiteit in Leuven, Belgium (2004). In 2002 he received the Quazza medal from IFAC, and in 2003 the Hendryk W. Bode Lecture Prize from the IEEE Control Systems Society.

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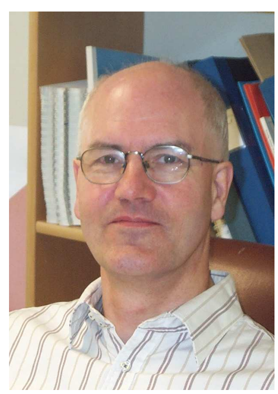
Torkel Glad is Professor of Nonlinear Control Systems in the department. Hewas born in Lund, Sweden in 1947. He received his M. Sc. degree in engineering physics in 1970 and the Ph. D. degree in automatic control in 1976, both from the Lund Institute of Technology, Lund, Sweden. Since 1988 he is Professor in the department. His research interests include Nonlinear Systems, algebraic aspects of System Theory and Optimal Control.



E-mail: torkel@isy.liu.se

Mille Millnert is a Professor in the department. He was born in 1952 and received his M. Sc. in 1977 and his Ph. D. in Automatic Control 1982 from Linköping University. His research interests are Model Based Signal Processing, Parameter Estimation and the Combination of Numerical and Symbolical techniques in Signal Processing and Control. From July 1996 he was Dean of the School of Engineering at Linköping University and from October 2003 he is president of Linköping University

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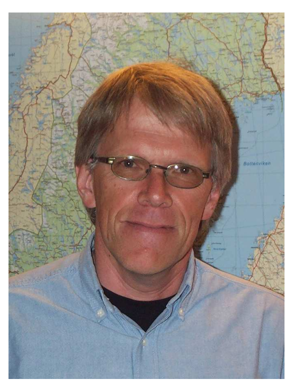
Svante Gunnarsson is Professor in the Control group, and was born in 1959. He received his M. Sc. in 1983, his Lic. Eng. in 1986 and his Ph. D. in 1988 all from Linköping University. From 1989 he was associate professor at the department, and from 2002 professor. His research interests are robotics, system identification, and iterative learning control.



E-mail: svante@isy.liu.se

Fredrik Gustafsson is Professor in Sensor Informatics at Department of Electrical Engineering, Linköping University, since 2005. He was born in 1964 and he received the M.Sc. degree in electrical engineering 1988 and the Ph.D. degree in Automatic Control, 1992, both from Linköping University. During 1992-1999 he held various positions in automatic control, and in 1999 he got a professorship in Communication Systems. His research interests are in statistical signal processing, adaptive filtering and change detection, with applications to vehicular, airborne, communication and audio systems. He was associate editor for IEEE Transactions of Signal Processing 2000-2006 and is currently associate editor for EURASIP Journal on Applied Signal Processing and International Journal of Navigation and Observation.

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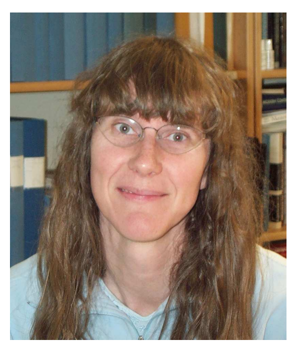
Inger Klein is an Associate Professor at the department. She was born in 1964. She received her M. Sc. in 1987, her Lic. Eng. in 1990, and her Ph. D. in 1993, all from Linköping University. Her research interest is diagnosis, fault detection and fault isolation, in particular for Discrete Event Systems.



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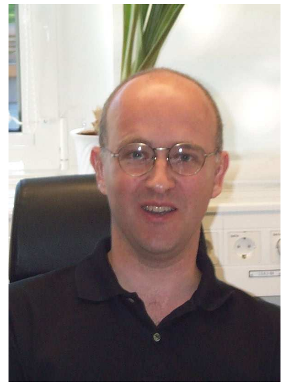
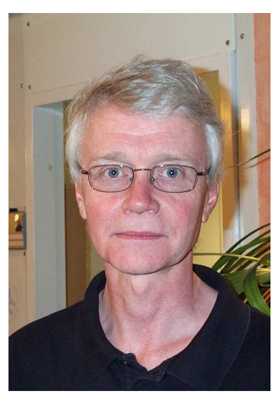
Anders Hansson is a Professor in the Control group, and he was born in Trelleborg, Sweden, in 1964. He received the M. Sc. 1989, Lic. Eng. in 1991, and the Ph. D. in 1995, all from Lund University, Lund, Sweden. From 1995 to 1998 he was employed by the Information Systems Lab, Stanford University. From 1998 to 2000 he was associate professor at Automatic Control, KTH, Stockholm. From 2001 he was an associate professor at the Division of Automatic Control, Linköping University. From 2006 he is professor at the same division. He is associate editor of IEEE Transactions on Automatic control. His research interests are applications of optimization to control and signal processing.



E-mail: hansson@isy.liu.se



Kent Hartman is a Junior Lecturer (universitetsadjunkt) in the Control Group. He was born in 1951, and received his M. Sc. in 1977 Applied Physics and Electrical Engineering at Linköping University, Department of Biomedical Engineering. He has been Director of Studies since 2000

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Anna Hagenblad is a Junior Lecturer in the Control Group. She was born in Lycksele, Sweden, in 1971, and she received her M. Sc. degree in Applied Physics and Electrical Engineering in 1995 and her Lic. Eng. in 1999. Her research interests are in the area of identification, particularly of the nonlinear Wiener model.

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Anders Helmersson is an Adjunct Professor at the Division of Automatic Control. He was born in 1957. In 1981, he received his M. Sc. in Applied Physics at Lund Institute of Technology. He has been with Saab Ericsson Space since 1984. In 1993 he joined the Control Group where he received his Ph. D. in 1995. His research interest is mainly in robust control and gain scheduling. He is currently employed by Saab AB.

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Alf Iskasson is an Adjunct Professor at the Division of Automatic Control. he was born in 1959, and he received his M. Sc. in 1983, his Lic. Eng. in 1986 and his Ph. D. in 1988, all from Linköping University. He is currently employed by ABB AB.

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Fredrik Gunnarsson is an Adjunct Lecturer in the division. He was born in 1971 He received his M. Sc. in Applied Physics and Electrical Engineering in 1996 his Lic. Eng. in 1998 and his Ph. D. in 2000, all at Linköping University. His current research interests include control theory and signal processing aspects of wireless communications. He also works as a Senior Research Engineer at Ericsson Research.

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Mikael Norrlöf is a Research Assistant in the Control Group, and he was born in 1971. He received his M. Sc. in Computer Science and Engineering 1996, his Lic. Eng. in 1998 and his Ph. D. in 2000, all at Linköping University. His current research interests include Iterative Learning Control, modeling, nonlinear control, trajectory generation, sensor fusion applications, and identification of industrial robots.

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Johan Löfberg is a Research Assistant in the Control Group, and he was born in 1974. He received his M.Sc. in Mechanical Engineering in 1998 and his Lic.Eng. in 2001 and his PhD in 2003 all at Linköping University. During 2003 - 2006 he was employed as a post doctoral fellow at ETH, Zürich.

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Jacob Roll is a Research Assistant in the Control Group. He was born in 1974. He received his M. Sc. in Applied Physics and Electrical Engineering in 1999 and his Lic. Eng. in 2001 and his Ph. D. in 2003 all at Linköping University. His research interests are in system identification and hybrid systems.

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Rickard Karlsson is a Research Assistant in the Division of Automatic Control, and he was born in 1970. He received his M. Sc. in Applied Physics and Electrical Engineering in 1996, his Lic. Eng. in 2002 and his Ph. D. in 2005 all at Linköping University.

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Martin Enqvist is a researcher associated with the Control Group. He was born in 1976. He received his M. Sc. in Applied Physics and Electrical Engineering in 2000, his Lic. Eng. in 2003 and his Ph. D. in 2005 all at Linköping University. He spent 2006 as a Postdoc researcher at the ELEC department, Vrije Universiteit Brussel, Belgium.

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Ragnar Wallin is a researcher associated with the Control Group. He was born in 1962. He received his M. Sc. in Electrical Engineering in 1998 and his Lic. Eng. in 2000 both from the Royal Institute of Technology, Stockholm and his Ph. D. in 2005 at Linköping University. His research interests are in optimization algorithms, mainly for gain scheduling applications.

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Jonas Jansson is a researcher associated with the Control Group. He was born in 1973. He received his M. Sc. in Applied Physics and Electrical Engineering in 1999, his Lic. Eng. in 2002 and his Ph. D. in 2005 all at Linköping University. He is employed by Volvo AB.

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Thomas Schön is a Ph.D. student in the department. He was born in 1977. In 2001 he received his BSc degree in Business Administration and Economics, and his M. Sc. degree in Applied Physics and Electrical Engineering, his Lic. Eng. in 2003 and his Ph. D. in 2006, all at Linköping University. His research interests are in signal processing, sensor fusion and system identification. He is now employed as a Research Assistant on the Division of Automatic Control.

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Ingela Lind is a Ph.D. student in the department. She was born in 1975. She received her M. Sc. in Applied Physics and Electrical Engineering in 1998, her Lic. Eng. in 2001 and her Ph. D. in 2006 all at Linköping University. She is now employed by Saab AB, Linköping.

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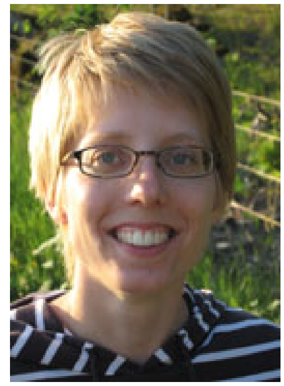

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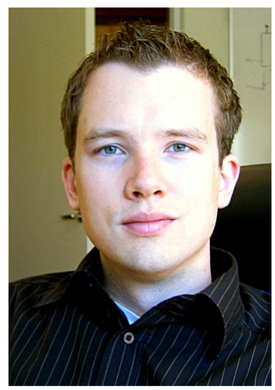

Andreas Eidehall is a Ph.D. student in the department. He was born in 1977. He received his M. Sc. in Applied Physics and Electrical Engineering in 2002 and his Lic. Eng. in 2004 both at Linköping University. He is employed by Volvo Car Corporation.

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Sören Hansson is employed as research engineer at the Division on a part time basis, where he is responsible for the laboratory equipment.

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Ulla Salaneck is the very valuable secretary for the control group.

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Visitors

Kjell-Magne Fauske Ph.D. student at the Norwegian University of Science and Technology (NTNU) and the University graduate center (UniK), located at Kjeller, from visited the division from October 2006 to March 2007.

Xiao-Li Hu Chinese Academy of Sciences, Beijing, China is a Post-doc at the Division from August 2006 - August 2007.

Appendix B

Courses

B.1 Undergraduate Courses

M.Sc. (civ.ing.)-program

- *Automatic Control* (Reglerteknik) The basic control course given for all engineering programs. *Contents*: The feedback concept, PID-controllers, Frequency domain design techniques, Sensitivity and robustness, State space models and state feedback controllers, Observers.

  M Mechanical Engineering. 134 participants. Lecturer: Inger Klein.

  Y Applied Physics and Electrical Engineering. 110 participants. Lecturer: Lennart Ljung.

  D Computer Engineering. 70 participants. Lecturer: Rickard Karlsson.

  I Industrial Engineering and Management. 166 participants. Lecturer: Svante Gunnarsson.

  TB, KB Engineering Biology and Chemical Biology Programs. 93 participants. Lecturer: Thomas Schön.

- *Control Theory Y* (Reglerteori Y). For the Applied Physics and Electrical Engineering and Computer Science and Engineering Programs. Multivariable systems, Fundamental limitations in feedback control systems, LQG-control, Loop transfer recovery, Loop shaping methods, Nonlinear systems, Optimal control. 82 participants. Lecturer: Torkel Glad.

- *Control Theory I* (Reglerteori I) For the Industrial Engineering and Management and Mechanical Engineering Programs. Multivariable systems, Sampled data systems, LQG-control. 13 participants. Lecturer: Torkel Glad.

- *Automatic Control M, advanced course* (Reglerteknik, fortsättningskurs M). For the Mechanical Engineering Program. Multivariable systems, Nonlinear systems, Signal processing. 15 participants. Lecturer: Svante Gunnarsson.

- *Digital Signal Processing* (Digital Signalbehandling). For the Applied Physics and Electrical Engineering and Computer Science and Engineering Programs. Spectral analysis, Filtering, Signal Modeling, Wiener and Kalman filtering, Adaptive filters. 109 participants. Lecturer: Fredrik Gustafsson.

- *Modelling and Simulation* (Modellbygge och Simulering). For the Applied Physics and Electrical Engineering program. Physical system modelling, Bond graphs, Identification methods, Simulation. 116 participants. Lecturer: Jacob Roll.

- *Digital Control* (Digital Styrning). For the Applied Physics and Electrical Engineering, Computer Science and Engineering and Industrial Engineering and Management Programs. Numerical control, binary control and PLCS, process computers and applications of digital process control. 107 participants. Lecturer: Anders Hansson.

- *Real Time Process Control* (Realtidsprocesser och reglering). For the Information Technology Program. Real time systems. PID control. 20 participants. Lecturer: Inger Klein.

- *Linear Feedback Systems* (Återkopplade linjära system). For the Information Technology Program. Linear systems, controllability, observability, feedback control. 20 participants. Lecturer: Inger Klein.

- *Control Project Laboratory* (Reglerteknisk projektkurs) For the Applied Physics and Electrical Engineering and Computer Science and Engineering Programs, Modelling and identification of laboratory processes, Controller design and implementation, 67 Participants. Lecturer: Anders Hansson.

- *Introduction to MATLAB* (Introduktionskurs i MATLAB). Available for several Engineering Programs. 540 participants. Lecturer: Jacob Roll/Ragnar Wallin.

- *Project work* (Ingenjörsprojekt Y). Develop an understanding of what engineering is all about and how the work is performed. - Administration, planning, communication, documentation and presentation of project work, 12 participants. Lecturer: Anders Hansson and Kent Hartman.

- *Perspectives to computer technology* (Perspektiv på datateknik). Project work with focus on computer technology, 6 participants. Lecturer: Kent Hartman.

B.Sc. (tekn.kand.) - program

- *Automatic control, EI* (Electrical Engineering) 5 units, 19 participants. Contents: Dynamical systems, the feedback principle, frequency domain analysis and design of control systems, robustness and sensitivity of control systems, sampling, implementation, some examples of nonlinearities in control systems. Simulation of dynamic systems. Lecturer: Kent Hartman.

- *Automatic control, advanced course, EI* 2 units, 64 participants. Contents: Sequential control and logic controllers. A typical industrial control system. Lecturer: Kent Hartman.

- *Automatic control, MI/KI* (Mechanical Engineering and Chemical Engineering) 4 units, 64 participants. Contents: Sequential control and logic controllers. Fundamentals of automatic control, dynamical systems, feedback, differential equations, frequency analysis, Bode plots, stability, simple controllers, sampling, implementation, simulation of dynamic systems. Lecturer: Kent Hartman and Ragnar Wallin.

B.2 Graduate Courses

- *System Identification.* Lecturer: Lennart Ljung. Literature: L. Ljung, System Identification: Theory for the User. Prentice Hall 1999, 2nd ed.

- *Linear systems.* Lecturer: Torkel Glad. Literature: Wilson J. Rugh, Linear System Theory, Prentice Hall, 1996.

Appendix C

Seminars

- *Brake systems - more than just dissipating kinetic energy*, **Jörg Sturmhoebel**, Project Manager NIRA Dynamics AB (Audi AG) and **Urban Forssel**l, NIRA Dynamics AB, January 26, 2006.

- *Variable rate filtering methods: Evasive targets, particles and point processes*, **Simon Godsill**, University of Cambridge, Cambridge, England, February 9, 2006.

- *The Attitude and Orbit Control System on the SMART-1 Lunar Probe*, **Per Bodin Rymdbolaget**, February 16, 2006.

- *Some examples of industrial R&D in Control & Optimization*, **Alf Isaksson**, ABB AB, February 23, 2006.

- *Observer design for a general electrical diode network - application for an industrial power converter*, **Anders Hultgren**, Högskolan i Kalmar, March 9, 2006.

- *Resource-Constrained Embedded Control and Computing Systems*, **Dan Henriksson**, Lunds universitet, Lund, March 16, 2006.

- *Modelling of curl and twist in multi-ply paperboard*, **Gianantonio Bortolin**, Royal Institute of Techonolgy, Stockholm, March 23, 2006.

- *MIGO and AMIGO Design of PID Controllers*, **Tore Hägglund**, Lund University, Lund, Sweden. April 6, 2006.

- *Vizualization of large-scale and complex medical data*, **Anders Ynnerman**, ITN, Linköping university, Aptil 20, 2006.

- *Tractable Problems in Optimal Decentralized Control*, **Michael Rotkowitz**, April 27, 2006.

- *Linear regression with a sparse parameter vector*, **Yngve Selen**, Uppsala University, Uppsala, May 4, 2006.

- *Errors-in-variables Methods in System Identification*, **Torsten Söderström**, Uppsala university, May 11, 2006.

- *Reglerteknikutmaningar för kemiindustrin*, **Krister Forsman**, Perstorp Speciality Chemicals AB, Lund, May 16, 2006.

- *Automotive Collision Avoidance Theory in Practice*, **Jonas Jansson**, Volvo PV AB, Göteborg, May 18, 2006.

- *Prediction of properties of a distillation unit to be used in advanced control*, **Tomas Montin**, Nynäs Pretrolium AB, May 23, 2006.

- *Cooperative transmit diversity based on superposition coding*, **Erik G. Larsson**, Royal Institute of Technology, Stockholm, June 1, 2006.

- *Graphical Models, Distributed Fusion, and Sensor Networks*, **Alan Willsky**, MIT, Cambridge, MA, June 12, 2006.

- *On performance and scalability issues in the consensus problem* **Alberto Speranzon**, Royal Institute of Technology, Stockholm, September 14, 2006.

- *Control and system theory for biochemical reaction networks; System reduction for glycolysis in yeast based on linearization, balancing, and truncation*, **Hanna Härdin and Jan van Schuppen**, CWI, Amsterdam, The Neterhalnds, September 15, 2006.

- *Challenges and tools for converter control in traction applications*, **Henrik Mosskull**, Bombardier, Västerås, September 28, 2006.

- *Tensor computations*, **Lars Eldén**, Department of Mathematics, Linköpings universitet, October 5, 2006.

- *Modelling and fault diagnosis of quantised systems: Theory and application examples*, **Jan Lunze**, -Ruhr Universität, Bochum, Germany, October 12, 2006.

- *Model based diagnostics in industrial setting*, **Johan Gunnarsson**, Sörman Information and Media, Linköping, October 19, 2006.

- *Feeding strategies based on probing control for E coli cultivations*, **Lena de Maré**, Lund Univesity, Lund, October 26, 2006.

- *Autonomous underwater vehicle (AUV) navigation*, **Kjell Magne Fauske**, University Graduate Center, Kjeller, Norway.

- *Generalized linear dynamic factor models*, **Manfred Deistler**, TU, Vienna, Austria, November 9, 2006.

- *Tracking of extended objects using radar detections*, **Fredrik Bengtsson**, Volvo, 3P, Göteborg, November 14, 2005.

- *Obemannade helikoptrar, från rotordynamik till autonom styrning*, **Erik Skarman**, Saab AB, Linköping, November 16, 2006.

- *Bandwidth-reduced linear models of a non-continuous power system component*, **Jonas Persson**, Svenska Kraftät, November 23, 2006.

- *Application of neuro-fuzzy approach to modelling and control of anaerobic degradation of organic waste*, **Snejana Yordanova**, Technical university of Sofia, Sofia, Bulgaria, November 29, 2006.

- *OpenModelica: A free open-source environment for system modeling, simulation, and teaching*, **Peter Fritzson**, Department of computer Science, Linköpings universitet, November 30, 2006.

- *LTV model reduction with error bounds*, **Anders Helmersson**, Saab AB, Linköping, December 7, 2006.

- *Convergence of numerical methods for optimal control using viscosity solutions and differential inclusions*, **Mattias Sandberg**, Royal Institute of Technology, Stockholm, December 14, 2006.

Appendix D

Travels and Conferences

Daniel Ankelhed participated at Reglermöte, Stockholm, Sweden, May 30-31.

Daniel Axehill visited the Department of Electrical Engineering, University of California Los Angeles, Los Angeles, USA during September 25 to December 21. He participated at Reglermöte 2006, Stockholm, Sweden, May 30-31 and at the 45th IEEE Conference on Decision and Control, San Diego, USA, December 13-15. July 10.

Andreas Eidehall visited VISTA (Vision Science, Technology and Application) at NICTA in Canberra, Australia During Januari 12 - April 12. He participated in Reglermöte, Stockholm, Sweden, May 30-31; the IEEE Intelligent Vehicles 2006, Tokyo, Japan, June 13-15 and the IEEE Intelligent Transoporation Systems 2006, Toronto, Canada, September 17-20, 2006.

Martin Enqvist was employed as a post-doc researcher at Department ELEC, Vrije Universiteit Brussel, Belgium during 2006. He participated in the ICCoS Workshop, Brussels, Belgium, February 7; the 14th IFAC Symposium on System Identification, Newcastle, Australia, March 29-31; the Interuniversity Attraction Poles Study Day, Louvain-la-Neuve, Belgium, May 16; the ERNSI and Forever Ljung Workshops, Linköping, Sweden, September 20-22; the Interuniversity Attraction Poles Study Day, Leuven, Belgium, October 24; the ICCoS Workshop, Leuven, Belgium, December 20; and visited the Department of Automatic Control at Lund University, Sweden on May 11.

Fredrik Gunnarsson participated the 12th Swedish Workshop on Wireless Systems, Bjärkaskog, Sweden, and visited KTH, Stockholm, June 2005 as Licantiate opponent, and ITN, Norrköping September 2005 as a committee member.

Svante Gunnarsson participated at Reglermöte, Stockholm, Sweden, May 30-31.

Fredrik Gustafsson participated in the ABB Diagnostic day (Västerås, February, 2006), ProFusion (EU project) annual workshop (Brussels, March 2006), Reglermötet (biannual Swedish control meeting, Stockholm, May, 2006), XXVI European Meeting of Statisticians (Torun PL, July, 2006), Particle filtering workshop (Oxford, July, 2006)

Anna Hagenblad participated in Reglermöte 2006, May 30-31 in Stockholm, Sweden.

Anders Hansson participated at Reglermöte, Stockholm, Sweden, May 30-31; 45th IEEE Conference on Decision and Control, San Diego, USA, December 13-15.

Janne Harju took part in Reglermöte 2006, May 30-31, in Stockholm, Sweden and in the 45th IEEE Conference on Decision and Control San Diego, CA USA, December 13-15.

Kent Hartman visited Högskoleverket, Stockholm April 5, Tekit-dagen, Linköping April 28, Reglermöte, Stockholm May 29-31, CDIO Workshop and Confrence, Linköping June 12-14, Forever Ljung, Linköpng Sep 22. He participated at "Samverkansgruppen för högskoleingenjörsutbildningar", Stockholm Mars 9 and April 27 and at Linköping Oct 4-5,

Anders Helmersson was opponent on Oskar Nilsson's licentiate thesis with the title "Modeling and Model Reduction in Automotive Systems". The thesis was defended on December 20 at the Department of Automatic Control, Lund University, Lund, Sweden.

Gustaf Hendeby participated at IEE Seminar on Target Tracking: Algorithms and Applications,Birmingham, United Kingdom, March 7–8; at

Reglermöte 2006, Stockholm, Sweden, May 30–31; at ;6th IFAC Symposium on Fault Detection, Supervision and Safty of Technical Processes, Beijing, P. R. China, August 30–September 1; and at NSSPW Nonlinear Statistical Workshop, Cambridge, United Kingdom, September 13–14, 2006.

Jeroen Hol participated at the International conference on information fusion, Florence, Italy, July 09-14. He attended the SLAM Summer School, Oxford, United Kingdom, Augustus 27-31. He participated at the Nonlinear Statistical Signal Processing Workshop, Cambridge, United Kingdom, September 09-16. Furthermore, participated at the project meetings for the EU project MATRIS in London, United Kingdom, May 22-24, September 1 and Darmstadt, Germany, October 10.

Rickard Karlsson participated in Big Sky, USA IEEE Aerospace Conference in Big Sky, STATE??, USA, March ??? , visited Lund University on April 12, took part in Reglermöte 2006 in Stockholm, May 30-31, took part in Nonlinear statistical signal processing conference, September ?? at University of Cambridge and spent October - December as a postdoc at University of Cambridge.

Lennart Ljung particpated in

8-9 feb: Microsymposium on System Identification, The Free University of Brussels, Brussels, Belgium, on February 8 and 9, the 14th IFAC Symposium on System Identification, SYSID'06 , Newcastle, Australia on March 29 – 31 and Reglermöte 2006 in Stockholm on May 29 – 31. On June 20 he was a Member of a thesis committee, University of Delft, the Netherlands and on August 29 – 30 he took part in the 5th Swedish Russian Conference of Control, Lund, Sweden, and December 5 – 8 he participated in the 9th International Conference on Control, Automation, Robotics and Vision, ICARCV 2006, Singapore and finally on December 12 – 15 he took part in the 45th IEEE Conference on Decision adn Control, San Diego, CA.

Mikael Norrlöf participated in Reglermöte, Stockholm, Sweden, May 30-31.

Jacob Roll participated at the HYCON WP3 meetings in Vienna, Austria, February 10, and Dortmund, Germany, August 23; at the 14th IFAC

Symposium on System Identification, Newcastle, Australia, March 29-31; Reglermöte, Stockholm, Sweden, May 30-31; 5th Russian-Swedish Control Conference, Lund, Sweden, August 29-30; 45th IEEE Conference on Decision and Control, San Diego, USA, December 13-15; and visited Vrije Universiteit Brussel, Belgium, June 6, and Università di Siena, Italy, July 10.

Ulla Salaneck participated in the Reglermöte, Stockholm, Sweden, May 30-31 and Administratörskongressen 2006 in Stockholm, Sweden, 30 maj - 1 juni 2006.

Thomas Schön visited the Department of Engineering, University of Cambridge, Cambridge, United Kingdom during January 26-27. He visited the Department of Automatic Control, Lund University, Lund, Sweden on March 1. On March 8 he participated in the Profusion2 Workshop in Brussels, Belgium. He participated at the 14th IFAC Symposium on System Identification, Newcastle, Australia, March 29-31. During April he visited the School of Electrical Engineering and Computer Science, University of Newcastle in Newcastle, Australia. He visited the Department of Signals and Systems, Chalmers University of Technology, Göteborg, Sweden during May 14-18. On May 19 he visited the Systems Biology & Bioinformatics Group, Fraunhofer Chalmers Research Centre, Göteborg, Sweden. He participated at Reglermötet (Swedish conference, Automatic Control), Stockholm, Sweden during May 29-31. He participated at the IEEE Intelligent Vehicle Symposium, Tokyo, Japan, June 13-15. He participated at the 5th Swedish-Russian control conference, Lund, Sweden, August 29-30. During September 13-15 he participated in the Nonlinear Statistical Signal Processing Workshop, Cambridge, United Kingdom. He also participated at the project meetings for the EU project MATRIS in London, United Kingdom, May 22-23 and Darmstadt, Germany, October 10-11. Furthermore, he participated at numerous project meetings for the IVSS (SEFS) project in Göteborg thoughout the year.

David Törnqvist participated at the 6th IFAC Symposium on Fault Detection, Supervision and Safety of Technical Processes, Beijing, P.R. China, September, 2006.

Johanna Wallén participated at Reglermöte 2006, Stockholm, Sweden, May

30-31, 2006.

Erik Wernholt participated at at the 14th IFAC Symposium on System Identification, Newcastle, Australia, March 29-31; and 23rd IEEE Instumentation and Measurement Technology Conference, Sorrento, Italy, April 24-27.

Appendix E

Lectures by the Staff

- Daniel Axehill: *A Mixed Integer Dual Quadratic Programming Algorithm Tailored for MPC*, 45th IEEE Conference on Decision and Control, San Diego, USA, December 13-15, 2006.
- Daniel Axehill: *Mixed Integer Predictive Control Using a Tailored Mixed Integer Dual Quadratic Programming Algorithm*, Reglermöte 2006, Stockholm, Sweden, May 30-31, 2006.
- Andreas Eidehall: *Threat assessment of general road scenes using Monte Carlo sampling*, IEEE Intelligent Transoporation Systems 2006, Toronto, Canada, September 17-20, 2006.
- Martin Enqvist: *Linear Models of Nonlinear Systems*, Department ELEC, Vrije Universiteit Brussel, Belgium, February 16, 2006.
- Martin Enqvist: *Identification of Hammerstein Systems Using Separable Random Multisines*, 14th IFAC Symposium on System Identification, Newcastle, Australia, March 30, 2006.
- Martin Enqvist: *Linear Models of Nonlinear Systems*, Department of Automatic Control, Lund University, Sweden, May 11, 2006.
- Martin Enqvist: *Dimension Reduction in Nonlinear System Identification*, ERNSI Workshop, Linköping, Sweden, September 21, 2006.
- Fredrik Gustafsson: *Model-based and data-driven approaches to monitoring and fault detection.* Invited keynote talk at ABB Diagnostic day, Västerås, February, 2006.

- Fredrik Gustafsson: *Statistical signal processing approaches to fault detection*. Plenary talk at IFAC Workshop SAFEPROCESS. Beijing, August, 2006.

- Fredrik Gustafsson: *Marginalization Issues for the Particle Filter*. Particle filtering workshop, Oxford, July, 2006.

- Fredrik Gustafsson: *Marginalization issues in particle filtering*. Invited talk at XXVI European Meeting of Statisticians, Torun PL, July, 2006.

- Fredrik Gustafsson: *Automotive safety: sensor fusion challenges*. Plenary talk at Reglermötet (biannual Swedish control meeting), Stockholm, May, 2006.

- Fredrik Gustafsson: *Virtual sensors and situational awareness*. Academic keynote presentation at ProFusion (EU project) annual workshop, Brussels, March 2006.

- Janne Harju: *Utilizing low rank properties when solving KYP-SDPs* Reglermöte, May 30, Stockholm, Sweden.

- Janne Harju: *Utilizing low rank properties when solving KYP-SDPs* 45th IEEE Conference on Decision and Control, December 15, San Diego, CA USA.

- Gustaf Hendeby: *Recursive Triangulation Using Bearings-Only Sensors*, IEE Seminar on Target Tracking: Algorithms and Applications, Birmingham, United Kingdom, March 7, 2006.

- Gustaf Hendeby: *Detection Limits for Linear Non-Gaussian State-Space Models*, 6th IFAC Symposium on Fault Detection, Supervision and Safty of Technical Processes, Beijing, P. R. China, August 30, 2006.

- Gustaf Hendeby: *Performance Issues in Non-Gaussian Filtering Problems*, NSSPW Nonlinear Statistical Workshop, Cambridge, United Kingdom, September 13, 2006.

- Rickard Karlsson *Positioning and Control of an Unmanned Aerial Vehicle* 2nd int. CDIO conference, June 13-14, Linköping, Sweden.

- Rickard Karlsson *The Marginalized Particle Filter in Practice* IEEE Aerospace conference, Big Sky, MT, USA, March 4-11.

- Rickard Karlsson: *Particle Filtering in Practice – Theory and Applications* November 23, University of Cambridge, Cambridge, England.

- Rickard Karlsson: *Particle Filtering for Positioning and Tracking Applications*, April 12, Lund University, Lund, Sweden.

- Lennart Ljung: *Obemanade farkoster och hjärnvisualisering – en presentation av MOVIII*, Meeting arranged by The Foundation for Strategic Research, Stockholm, Sweden, March 15, 2006.

- Lennart Ljung: *Identification of Wiener System with monotonous nonlinearity*, 14th IFAC Symposium on System Identification, Newcastle, Australia, March 30, 2006.

- Lennart Ljung: *An Integrated system identification toolbox for linear and nonlinear models*, 14th IFAC Symposium on System Identification, Newcastle, Australia, March 30, 2006.

- Lennart Ljung: *A (simplistic) perspective on nonlinear system identification*, 14th IFAC Symposium on System Identification, Newcastle, Australia, March 39, 2006.

- Lennart Ljung: *Personal Comments on Nonlinear system identification*, Round table discussion, 14th IFAC Symposium on System Identification, Newcastle, Australia, March 31, 2006.

- Lennart Ljung: *Identification of Wiener System with monotonous nonlinearity*, The 3rd Swedish-Chinese Conference on Control, Linköping, May 19, 2006.

- Lennart Ljung: *Identification of Nonlinear Dynamical Systems*, Plenary presentation at the 9th International COnference on Control, Automation, Robotics and Vision, ICARCV 2006, Singapore, Secember 7, 2006..

- Jacob Roll: *Direct Weight Optimization for Approximately Linear Functions: Optimality and Design*, 14th IFAC Symposium on System Identification, Newcastle, Australia, March 29-31, 2006.

- Jacob Roll: *Connections between optimisation-based regressor selection methods and analysis of variance*, Reglermöte, Stockholm, Sweden, May 30-31, 2006.

- Jacob Roll: *Connections between optimisation-based regressor selection methods and analysis of variance*, Vrije Universiteit Brussel, Belgium, June 6, 2006.
- Jacob Roll: *Connections between optimisation-based regressor selection methods and analysis of variance*, Università di Siena, Italy, July 10, 2006.
- Jacob Roll: *Connections between optimisation-based regressor selection methods and analysis of variance*, 5th Russian-Swedish Control Conference, Lund, Sweden, August 29-30, 2006.
- Jacob Roll: *Studying internalisation of insulin receptors via greybox identification*, poster at ERNSI Workshop, Linköping, September 20-21, 2006.
- Jacob Roll: *Connections between optimisation-based regressor selection methods and analysis of variance*, 45th IEEE Conference on Decision and Control, San Diego, USA, December 13-15, 2006.
- Thomas Schön: *Nonlinear System Estimation - with Automotive Applications*, January 27, Department of Engineering, University of Cambridge, Cambridge, United Kingdom.
- Thomas Schön: *Solving Estimation Problems for Automotive Applications*, March 1, Department of Automatic Control, Lund University, Lund, Sweden.
- Thomas Schön: *Maximum Likelihood Nonlinear System Estimation*, March 31, 14th IFAC Symposium on System Identification, Newcastle, Australia.
- Thomas Schön: *Exploiting Structure using the Marginalized Particle Filter*, May 16, Department of Signals and Systems, Chalmers University of Technology, Göteborg, Sweden.
- Thomas Schön: *Estimation of Nonlinear Systems using Particle Filters*, May 19, Systems Biology & Bioinformatics Group, Fraunhofer Chalmers Research Centre, Göteborg, Sweden.

- Thomas Schön: *Lane Depatrure Detection for Improved Road Geometry Estimation*, May 30, Reglermötet (Swedish conference, Automatic Control), Stockholm, Sweden.

- Thomas Schön: *Lane Depatrure Detection for Improved Road Geometry Estimation*, June 15, IEEE Intelligent Vehicle Symposium, Tokyo, Japan.

- Thomas Schön: *Introducing the Marginalized Particle Filter*, August 30, 5th Russian-Swedish Control Conference, Lund, Sweden.

- Thomas Schön: *State-of-the-art for the Marginalized Particle Filter*, September 14, Nonlinear Statistical Signal Processing Workshop, Cambridge, United Kingdom.

- Thomas Schön: *Introducing the Marginalized Particle Filter - Exploiting Structures in State-Space Models*, September 21, ERNSI (EU Network of Excellence), Linköping, Sweden.

- Thomas Schön: *Starting Point Tracking System for SEFS - Implementation and Short Background*, IVSS (SEFS) Workshop, Göteborg, Sweden.

- David Törnqvist: *Eliminating the Initial State for the Generalized Likelihood Ratio Test*, 6th IFAC Symposium on Fault Detection, Supervision and Safety of Technical Processes, Beijing, P.R. China, September, 2006.

- David Törnqvist: *Statistical Fault Detection with Applications to IMU Disturbances*, Licentiate thesis presentation, Linköpings universitet, Linköping, Sweden, June 9, 2006.

- David Törnqvist: *Positioning and Control of an Unmanned Aerial Vehicle: Project Supervision issues in a CDIO-Project Course*, CUL pedagogic conference, Linköpings universitet, Linköping, Sweden, November 8-9, 2006.

- Johanna Wallén: *Derivation of kinematic relations for a robot using Maple*, Reglermöte 2006, Stockholm, Sweden, May 30-31, 2006.

- Erik Wernholt: *Nonlinear Identification of a Physically Parameterized Robot Model*, 14th IFAC Symposium on System Identification, Newcastle, Australia, March 29-31, 2006.

- Erik Wernholt: *Detection and Estimation of Nonlinear Distortions in Industrial Robots*, 23rd IEEE Instumentation and Measurement Technology Conference, Sorrento, Italy, April 24-27, 2006. Also held at the 15th ERNSI Workshop, Linköping, Sweden, 20-21 September.

Appendix F

Publications

Phd Theses

[1] A. Eidehall. *Tracking and threat assessment for automotive collision avoidance*. PhD thesis, Dec. 2006. URL http://www.control.isy.liu.se/publications/doc?id=1891.

[2] M. Gerdin. *Identification and Estimation for Models Described by Differential-Algebraic Equations*. PhD thesis, Linköping university, SE-581 83 Linköping, Sweden, Nov. 2006. URL http://www.control.isy.liu.se/publications/doc?id=1865.

[3] J. Gillberg. *Frequency Domain Identification of Continuous-Time Systems*. PhD thesis, Sept. 2006. URL http://www.control.isy.liu.se/publications/doc?id=1915.

[4] C. Grönwall. *Ground Object Recognition using Laser Radar Data - Geometric Fitting, Performance Analysis, and Applications*. PhD thesis, Oct. 2006. URL http://www.control.isy.liu.se/publications/doc?id=1869.

[5] I. Lind. *Regressor and Structure Selection - Uses of ANOVA in System Identification*. PhD thesis, Linköpings universitet, SE-581 83 Linköping, May 2006. URL http://www.control.isy.liu.se/publications/doc?id=1809.

[6] T. Schön. *Estimation of Nonlinear Dynamic Systems - Theory and Applications*. PhD thesis, Linköping, Sweden, Feb. 2006. URL http://www.control.isy.liu.se/publications/doc?id=1791.

Licentiate Theses

[7] J. Sjöberg. Some results on optimal control for nonlinear descriptor systems. Technical Report Licentiate Thesis no. 1227, Department of Electrical Engineering, Linköping University, SE-581 83 Linköping, Sweden, Jan. 2006. URL http://www.control.isy.liu.se/publications/doc?id=1792.

[8] D. Törnqvist. Statistical fault detection with applications to imu disturbances. Technical Report Licentiate Thesis no. 1258, Department of Electrical Engineering, Linköping University, SE-581 83 Linköping, Sweden, June 2006. URL http://www.control.isy.liu.se/publications/doc?id=1830.

Books

[9] T. Glad and G. Hendeby, editors. *Forever Ljung in System Identification*. Studentlitteratur, Lund, 2006.

[10] T. Glad and L. Ljung. *Reglerteknik, Grundläggande teori*. Studentlitteratur, Lund, 2006. 4:th edition.

Journal Papers and Book Chapters

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153(4):345–351, Aug. 2006. URL http://www.control.isy.liu.se/publications/doc?id=1806.

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Conference Papers

[24] D. Axehill and A. Hansson. Mixed integer predictive control using a tailored mixed integer dual quadratic programming algorithm. In *Proceedings of Reglermöte 2006*, Stockholm, Sweden, May 2006. URL http://www.control.isy.liu.se/publications/doc?id=1902.

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Appendix G

Technical Reports

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Appendix H

Master's Theses

[112] M. Alkeryd. Evaluation of position sensing techniques for an unmanned aerial vehicle. Master's thesis no LiTH-ISY-EX-3790, Department of Electrical Engineering, Linköping University, 2006.

[113] E. Almgren. Sensor fusion for enhanced lane departure warning system. Master's thesis no LiTH-ISY-EX-3829, Department of Electrical Engineering, Linköping University, 2006.

[114] J. Betshammar. Improved billet shape modeling in optimization of the hot rod and wire rolling process. Master's thesis no LiTH-ISY-EX-3906, Department of Electrical Engineering, Linköping University, 2006.

[115] E. Carlsson. Modeling hydrostatic transmission in forest vehicle. Master's thesis no LiTH-ISY-EX-3801, Department of Electrical Engineering, Linköping University, 2006.

[116] J. Eklånge. Design and implementation of a test rig for a gyro stabilized camera system. Master's thesis no LiTH-ISY-EX-3753, Department of Electrical Engineering, Linköping University, 2006.

[117] H. Engdahl. Solving a dead-lock problem for nfo sinus. Master's thesis no LiTH-ISY-EX-3945, Department of Electrical Engineering, Linköping University, 2006.

[118] O. Enqvist. Afs-assisted trailer reversing. Master's thesis no LiTH-ISY-EX-3752, Department of Electrical Engineering, Linköping University, 2006.

[119] M. Eriksson and B. Wedell. Performance estimation of a ducted fan uav. Master's thesis no LiTH-ISY-EX-3795, Department of Electrical Engineering, Linköping University, 2006.

[120] P. Eriksson. Recursive grey-box identification of transmission of an industrial robot. Master's thesis no LiTH-ISY-EX-3841, Department of Electrical Engineering, Linköping University, 2006.

[121] K. Fredman and A. Freiholtz. Use of simulation optimization for clearance of flight control laws. Master's thesis no LiTH-ISY-EX-3786, Department of Electrical Engineering, Linköping University, 2006.

[122] N. Gustavsson. The use of positioning systems for look-ahead control in vehicles. Master's thesis no LiTH-ISY-EX-3776, Department of Electrical Engineering, Linköping University, 2006.

[123] J. Heyman. Intercell interference management in an ofdma-based downlink. Master's thesis no LiTH-ISY-EX-3837, Department of Electrical Engineering, Linköping University, 2006.

[124] S. Johansson. Navigation and control of an autonomous ground vehicle. Master's thesis no LiTH-ISY-EX-3796, Department of Electrical Engineering, Linköping University, 2006.

[125] R. Mannale. Comparison of regressor selection methods in system identification. Master's thesis no LiTH-ISY-EX-3833, Department of Electrical Engineering, Linköping University, 2006.

[126] E. Narby. Modeling and estimation of dynamic tire properties. Master's thesis no LiTH-ISY-EX-3800, Department of Electrical Engineering, Linköping University, 2006.

[127] A. Nordström. Identification and control of an industrial robot using accelerometer. Master's thesis no LiTH-ISY-EX-3785, Department of Electrical Engineering, Linköping University, 2006.

[128] H. Ohlsson. Mathematical analysis of a biological clock model. Master's thesis no LiTH-ISY-EX-3663, Department of Electrical Engineering, Linköping University, 2006.

[129] M. Olofsson. Identification and simulation of a leslie cabinet. Master's thesis no LiTH-ISY-EX-3775, Department of Electrical Engineering, Linköping University, 2006.

[130] T. Svensson. Identification and simulation of a spring reverb. Master's thesis no LiTH-ISY-EX-3751, Department of Electrical Engineering, Linköping University, 2006.

[131] H. Thorell. Voice activity detection in the tiger platform. Master's thesis no LiTH-ISY-EX-3817, Department of Electrical Engineering, Linköping University, 2006.

[132] O. Thulin. Intermediate view interpolation of stereoscopic images for 3d-display. Master's thesis no LiTH-ISY-EX-3866, Department of Electrical Engineering, Linköping University, 2006.

[133] A. Toverland. Echo tracking for tank gauging applications using non model based methods. Master's thesis no LiTH-ISY-EX-3798, Department of Electrical Engineering, Linköping University, 2006.

[134] A. Tyrberg. Data transmission over speech coded voice channels. Master's thesis no LiTH-ISY-EX-3843, Department of Electrical Engineering, Linköping University, 2006.

[135] E. Ulfhielm. Modeling of metabolic insulin signaling in adipocytes. Master's thesis no LiTH-ISY-EX-3778, Department of Electrical Engineering, Linköping University, 2006.

[136] B. Wallebäck. Positioning estimation using eo/ir-sensors on a moving platform. Master's thesis no LiTH-ISY-EX-3810, Department of Electrical Engineering, Linköping University, 2006.

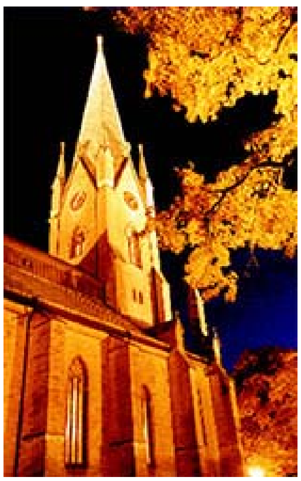
Appendix I

Conference Programs

After this page follows the programs for the three conferences and workshops that were organized by the division during 2006:

- The Third Swedish-Chinese Control Meeting, May 17 – 19.
- The ERNSI Workshop, September 20 – 21.
- The Workshop Forever Ljung in System Identification, September 22.

3rd Swedish-Chinese Conference on Control
Linköping University Linköping, Sweden on May 18-19, 2006



[welcome page] - [**program**] - [getting there] - [hotels]

Program of the Swedish-Chinese Conference on Control

PROGRAM

Wednesday, May 17, 2006

18-20 Welcome reception at Lennart Ljung's residence

Thursday, May 18, 2006

10.00 - 11.20 On Global Controllability of Some Classes of Affine Nonlinear Systems
Lei Guo, Chinese Academy of Sciences, Beijing

Distributed Sensor Network for Target Tracking
Xiaoming Hu, Royal Institute of Technology, Stockholm

Soft Control on Collective Behavior of a Group of Autonomous Agents by a Shill Agent
Jing Han, Chinese Academy of Sciences, Beijing

Distributed Cooperative Processing and Estimation over Wireless Sensor Networks
Bo Wahlberg and Carlo Fischione, Royal Institute of Technology, Stockholm

11.20 - 13.00 LUNCH

13.00 - 14-30 Irreducible Nonlinear Inversion and Its Application to Secure Communication
Yufan Zheng, East China Normal University, Shanghai

Model Reduction of LTV Systems

Anders Helmersson, Saab Ericsson Space AB and Linköping university, Linköping

Stabilization of Switched Linearizable Nonlinear Systems
Qiang Lu, Tsinghua university, Beijing and Daizhan Cheng and Feng Liu, Chinese Academy of Sciences, Beijing

An eigenvalue approach to the solution of constrained stochastic optimal control problems
Claes Breitholtz, Chalmers, Göteborg

14.30 - 15.00 BREAK

15.00 - 17.00 Random Sample Generations from Contractive Lower Triangular Block Toeplitz Matrices
Tong Zhou and Chao Feng, Tsinghua university, Beijing

A discussion of some robustness issues in experiment design for system identification
Håkan Hjalmarsson, Royal Institute of Technology, Stockholm

Recursive System Identification by Stochastic Approximation

Han-Fu Chen, Chinese Academy of Sciences, Beijing

On optimal linear quadratic distributed control
Anders Rantzer, Lund university, Lund

Semi-global Robust Stabilization of A Class of Feedforward Systems
Minghui Zhu and Jie Huang
The Chinese University of Hong Kong

Prototype of Novel Parallel Kinematic Manipulator
Rolf Johansson, Lund university, Lund

Reception given by the Provincial Governor of Östergötland, Björn Eriksson, at his Residence, Linköpings Slott, followed by the Conference Banquet

Friday, May 19, 2006

9.00 - 10.00 Global Controllability of Switched Affine Systems
Daizhan Cheng, Chinese Academy of Sciences, Beijing

Control Allocation and Optimal Control
Torkel Glad, Linköping university, Linköping

Non-smooth feedback and finite-time control
Yiguang Hong, Chinese Academy of Sciences, Beijing

10 - 10.30 BREAK

10.30 - 11.30 On Robust Stability Analysis of Networked Systems
Ulf Jönsson, Royal Institute of Technology, Stockholm

Measures of Stability and Instability
Li Qiu, University of Science and Technology, Hong Kong

Predictive control for hybrid vehicles using stochastic dynamic programming
Bo Egardt, Chalmers, Göteborg

11.30 - 12.40 LUNCH

12.40 - 14.30 Extending the Frisch scheme for errors-in-variables identification
to correlated output noise
Torsten Söderström, Uppsala university, Uppsala

Decentralized Adaptive Output-Feedback Stabilization for Large-Scale
Stochastic Nonlinear Systems
Shu-Jun Liu and Jifeng Zhang, Chinese Academy of Sciences, Beijing

Virtual-Constraints-Based Design of Stable Oscillations of the Furuta
Pendulum: Theory and Experiments
Leonid Freidovich, Umeå university, Umeå

Event-Based Optimization and Lebesgue Sampling
Xiren Cao, Hong Kong University of Science and Technology

Dynamic output feedback stabilization of the 3 state Moore-Greitzer
compressor model
Anton Shiriaev, Umeå university, Umeå

14.30 - 15.00 BREAK

15.00 - 16.30 Attractive Regions Formed by Environment
Hong Qiao, Chinese Academy of Sciences, Beijing

Two alternative views on control design with degree constraint
Anders Lindquist, Royal Institute of Technology, Stockholm

Optimization Based Production Scheduling with
Hybrid Dynamics and Constraints

Xiaohong Guan, Tsinghua university, Beijing

Identification of Wiener Systems with Monotonous Linearity

Lennart Ljung, Linköping university, Linköping

17.00 - 22.00 Boat trip on Lake Rengen and Dinner at Rimforsa Strand

Ulla Salaneck
Last modified: Tue April 18, 15:10:47 MET 2006

Responsible for this page: Ulla Salaneck , ulla@isy.liu.se

Page last update: 2006-09-18

ERNSI WORKSHOP 2006

Program

The chairmen are Lennart Ljung (organizer), Manfred Deistler and Zhang Qinghua.

September 20

Session 1 - Applications and Case-Studies

09:00 – 10:00 *Fredrik Gustafsson* (Linköping): Vehicle Safety: Challenges in Sensor Fusion

10:00 – 10:25 Break

10:25 – 10:50 *Erik Wernholt* (Linköping): Detection and Estimation of Nonlinear Distortions in Industrial Rob

10:50 – 11:10 Break

Session 2 – Postersession

11:10 – 12:00

Hanna Hardin (Vrije Universiteit/CWI): System Reduction of Biochemical Systems - Example of Glycolysis i

Bart Vanluyten, Jan C. Willems, Bart De Moor (KUL): Matrix Factorization and Stochastic State Representati

Stefano Perabo (INRIA): Adaptive Filtering for Linear Time-Variant Stochastic Systems with Disturbances

A. Rensfelt and T. Söderström (Uppsala):

Optimal Excitation for Nonparametric Identification of Viscoelastic Materials

Mei Hong, Torsten Söderström and Wei Xing Zheng (Uppsala): A Simplified Form of the Bias-Eliminating Le
Method for Errors-in-Variables Identification

Mei Hong, Torsten Söderström, Johan Schoukens and Rik Pintelon (Uppsala): A Comparison of time domain r
likelihood method and sample maximum likelihood method in Errors-in-variables Identification

Johan Paduart (VUB): Block-Oriented Nonlinear Models vs. Nonlinear State Space Models

Rickard Karlsson (Linköping): GPS-free Navigation at Sea using Particle Filters

Tom D'haene (VUB): System Identification with Constraints

Jacob Roll (Linköping): Biological applications

Frida Eng (Linköping): Identification with Stochastic Sampling Time Jitter

12:00 – 13:30 Lunch

Session 3 – System Identification of Biochemical Networks (organized by Jan v. Schupp

13:30 - 14:20 *Mans Ehrenberg* (Uppsala): Intracellular pathways and control systems: Modeling and experime of models

14:20 - 14:45 Discussion of this lecture

14:45 - 15:15 Break

15:15 - 16:00 *Elling W. Jacobsen* (KTH.SSS): On identification of genetic and metabolic networks

16:00 - 16:30 *Jan H. van Schuppen* (CWI/VU): Control and system theory of biochemical reaction networks

16:30 - 17:00 Discussion on system identification of biochemical reaction networks and of biological systems

Social Program

17:30 Busses leave for the **Flygvapenmuseum** and the Conference dinner

September 21

Session 4 – Statistics and System Identification

09:00 – 10:00 *Alessandro Chiuso* (Padova): Recent Development in Subspace Identification

10:00 – 10:20 Break

10:20 – 10:45 *Andrea Lecchini*(Cambridge): Performance of MCMC Optimization methods

10:45 – 11:10 *Jonas Mårtensson* (KTH): A Variance Expression for Scalar Quantities Estimated from Full Orc

11:10 – 11:35 *Steven Gillijns* (KUL): Linear Recursive Filtering with Noisy Input and Output Measurements

11:35 – 12:00 *Tomas Schön* (Linköping): Introducing the Marginalized Particle Filter - Exploiting Structures ir Models

12:00 – 13:30 Lunch

Session 5 – Nonlinear Systems

13:30 – 14:30 *Xavier Pennec* (INRIA): Statistical Computing on Manifolds: From Riemannian Geometry to Co
Anatomy

14:30 – 14:45 Break

14:50 – 15:10 *Martin Enqvist* (VUB): Dimension Reduction in Nonlinear System Identification

15:10 – 15:35 *Marcelo Espinoza* (KUL): Structured Kernel-based Modeling for Nonlinear System Identificatio

15:35 – 16:00 *Giovanna Fanizza* (KTH): Passivity-Preserving Model Reduction by Analytic Interpolation

16:00 – 16:25 *Ingela Lind* (Linköping): Regressor and Structure Selection in NARX models using ANOVA

16:25 – 16:50 *Laszlo Gerencser*: A Representation Theorem for the Error of Recursive Estimators

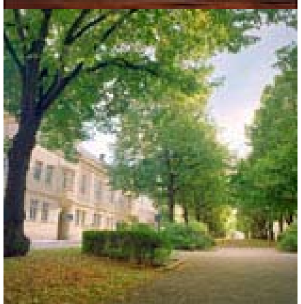
General Discussion

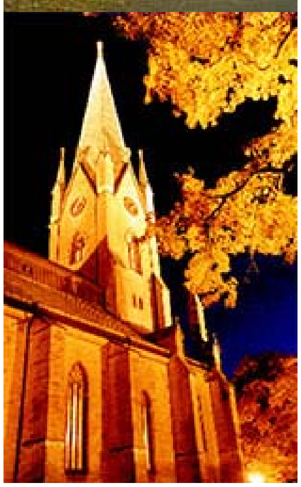
16:50 – 17:50

Automatic Control
Linköpings universitet
581 83 LINKÖPING
Tel: 013-28 10 00
Fax: 013-13 92 82

Forever Ljung - a workshop on the occasion of Lennart Ljung's 60th birthday

Collegium Conference Center in Linköping, Sweden on Friday, September 22, 2006





[welcome page] - [**program**] - [getting there] - [hotels] - [registration]

The workshop takes place at Collegium Conference Center.

Program:

8.15 - 8.25	Introduction: Mille Millnert, Rector Linköping university
8.25 - 8.30	Greetings from Thomas Kailath
8.30 - 10.00	*Chairman: Svante Gunnarsson*
	Lei Guo: On controllability of some classes of affine nonlinear systems.
	Boris Polyak: New challenges in nonlinear control: stabilization and synchronization of chaos.
	Keith Glover: Modelling IC engines: first principles, experiments and data analysis
10.00 - 10.30	Coffee
10.30 - 12.00	*Chairwoman: Inger Klein*
	Albert Benveniste: The local approach to change detection, diagnosis, and model validation: application to vibration mechanics.
	Torsten Söderström: Identifying Characteristics of viscoelastic materials from wave propagation experiments - recent advances.
	Stefan Nilsson: Theory and practice of desinformation and illusion.
12.00 - 13.30	Lunch
13.30 - 15.00	*Chairman: Fredrik Gustafsson*
	Graham Goodwin: Good, bad and optimal experiments for identification.
	Bo Wahlberg: A control perspective on optimal input design in system identification.
	Torkel Glad: Parametric identifiability from parameter-free equations - using model libraries.
15.00 - 15.30	Coffee
15.30 - 17.00	*Chairman: Anders Hansson*
	Peter Caines: Large population stochastic dynamicgames: the Nash certainty equivalence

	principle and adaptation.
	Karl Johan Åström: Adventures in system identification.
	Michel Gevers: System identification without Lennart Ljung: What would have been different?
17.15	Buses will leave for central Linköping
19.00	Banquet at Konsert & Kongress

last edited 7th of September 2006 by Frida Eng