LINKÖPING UNIVERSITY
DIVISIONS OF AUTOMATIC CONTROL AND COMMUNICATION SYSTEMS
ACTIVITY REPORT
2002

Contents

Chapter 1

Introduction

The Divisions of Automatic Control and Communication Systems consist of some forty persons. We teach thirteen undergraduate courses to more than eleven hundred students. The courses cover both traditional control topics and more recent topics in model building and signal processing.

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 utilize 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. Within the Competence Center ISIS 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*: Within ISIS we have a close cooperation with ABB Automation Technology Products – Robotics.

- *Optimization for Control and Signal Processing*: Convex optimization techniques are becoming more and more important for various control and signal processing applications. We study som such applications, in particular in connection with model predictive control.

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

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

The Control and Communication Divisions take active part in the VINNOVA Competence Center ISIS (Information Systems for Industrial Control and Supervision), whose Director is Lennart Ljung. The ISIS Center started in November 1995. Phase III of this Competence center started January 1, 2001 and lasts for three more years.

The divisions are also central partners in the Research School ECSEL (Excellence Center for Computer Science and Systems Engineering in Linköping), which started its activities during 1996. This research school is funded by the Foundation for Strategic Research (SSF) and is a joint effort between the departments of Electrical Engineering and Computer Science.

During the year Fredrik Tjärnström defended his PhD dissertation and Rickard Karlsson, Per-Johan Nordlund, Måns Östring, Claes Olsson, Jonas Jansson, Niclas Persson and David Lindgren their Lic. Eng. dissertations.

The Divisions hosted the biannual Swedish control conference "Reglermöte" in May 2002. The conference had about 230 participants an was preceded by special topic meetings on control education as well as meetings for doctoral students, administrators, and technical support personnel.

Also, in 2002 Lennart Ljung received *the Quazza Medal* from the International Federation of Automatic Control (IFAC) in connection with the triennal IFAC Congress in Barcelona.

At the same congress Fredrik Tjärnström was selected as one of three finalists for the *Young Author Prize*.

Moreover the Control and Communication group was selected as one of 10 "Excellent Research Environments" by the Swedish Research Council (VR). This involved an extra bonus grant for the years 2002 and 2003.

In the following pages the main research results obtained during 2002 are summarized. 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.


MATLAB
PREPRINTS
REGLERMÖTE 2002
29-30 MAJ 2002
REGLERTEKNIK &
KOMMUNIKATIONSSYSTEM
LINKÖPINGS UNIVERSITET

We invite you to visit our home page:

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

The competence center ISIS has the home page

`http://vir.liu.se/isis`

and for the research school ECSEL turn to

`http://vir.liu.se/ecsel`

Chapter 2

Network Services

There are a number of ways you can access the work produced at this group. Most convenient is probably electronic mail to 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 sent to our secretary Ulla Salaneck.

Finally you can also retrieve reports and software electronically either by using our FTP- or World Wide Web- services. This is our preferred method of distributing reports.

2.1 World Wide Web

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

`http://www.control.isy.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 will get the opportunity the bring home 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 comment, please send an email to our research engineer, Joakim Svensén:

`joasv@isy.liu.se`

2.2 Publications Data Base

Selecting "Publications" in our web pages gives access to our publications data base. See Figure 2.1. It allows you to search for publications by author, area, year and/or publication type. You can also search for words in the title. The result of the search is given either as a clickable list of publications (Choose HTML) or a list of BibTeX items (Choose Bibtex). See Figure 2.2 for an example of a search result. Clicking on the publication items brings you to the home page of the publication with further information. See Figure 2.3. Department reports can always be downloaded from the home page, while articles and conferenec papers refer to a related department report that can be downloaded in .ps or .pdf format.

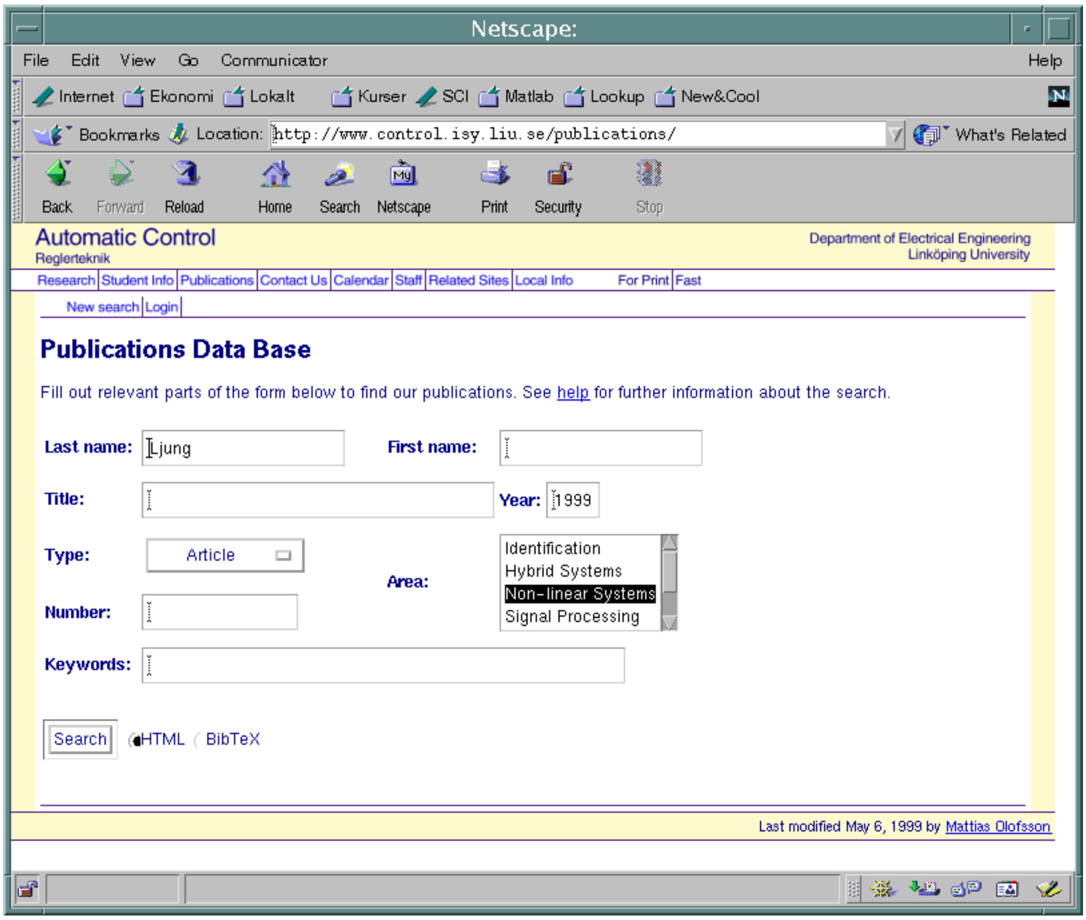

Figure 2.1: The publications data base interface

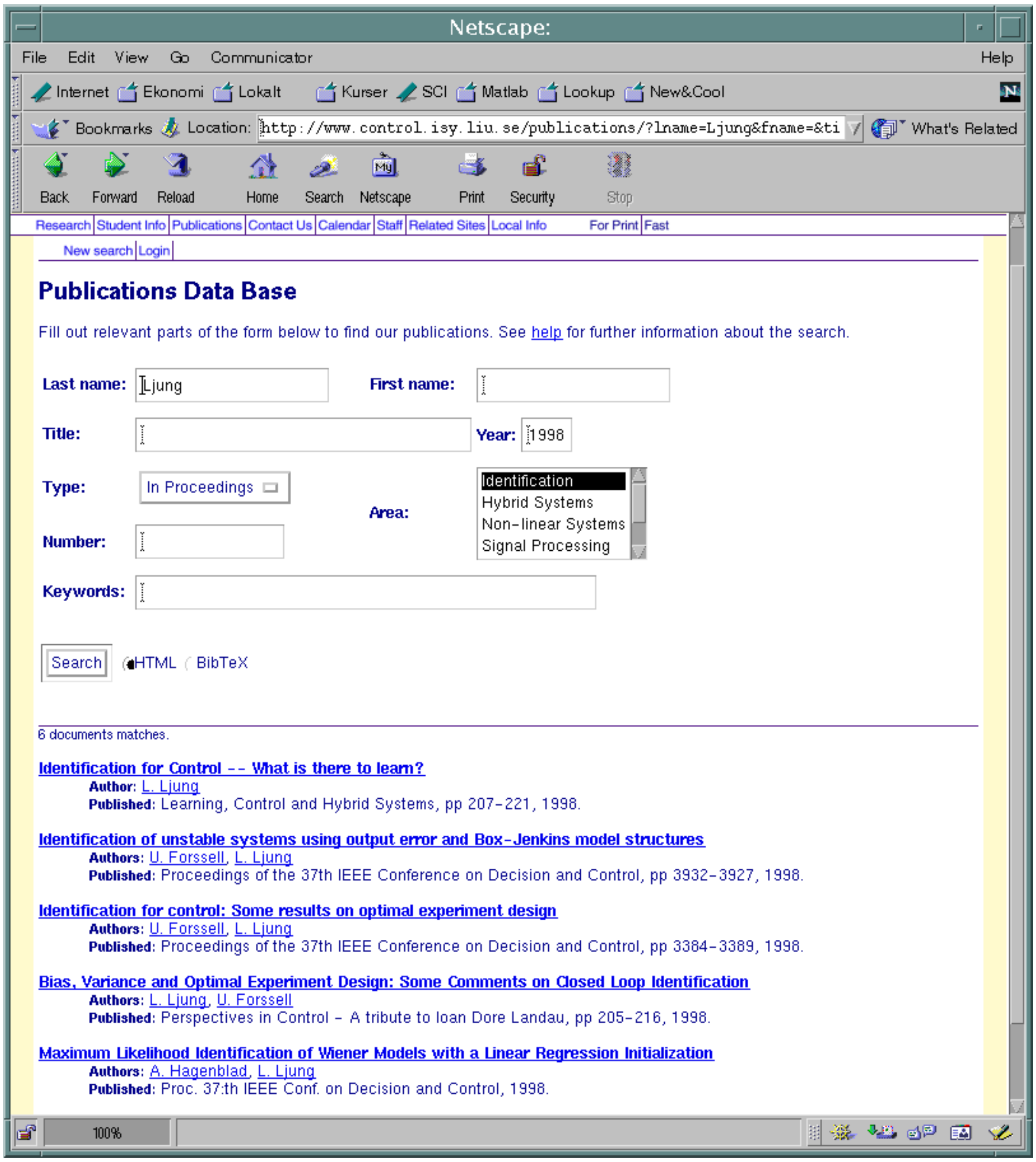

Figure 2.2: Example of search result

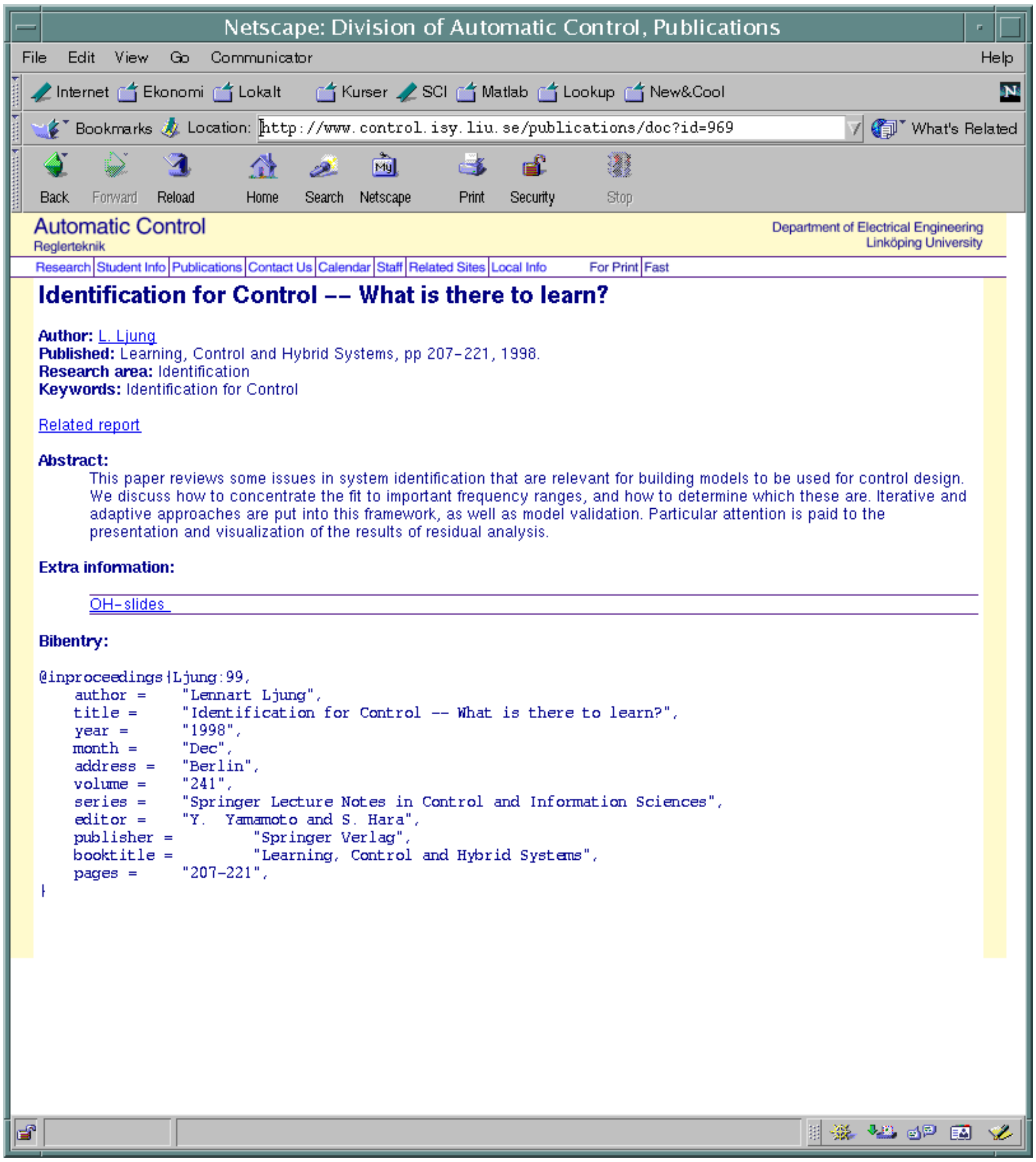

Figure 2.3: Example of a publication home page

Chapter 3

System Identification

3.1 Introduction

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

During 2002, one PhD-thesis, [1] and one licentiate theses, [7], have been finished in this area. These will be described in the next two sections.

3.2 Variance Expressions and Model reduction in System Identification

Fredrik Tjärnström's PhD-thesis [1] deals with how the variance of an estimated model is transformed and affected when the order of the estimated model is reduced.

In fact, estimating models from data by first estimating a high order model which is then subjected to model reduction could be an attractive approach to system identification. In this way it is possible to keep track of the bias errors that are (possibly) present in the low order model. Another important aspect is the variance of the reduced model. This leads us to the question: Will it ever be better to estimate a low order model via model reduction than estimating the low order model directly from data? This is one of the topics that are discussed in [1]. The somewhat surprising result is that using L_2 model reduction it could in some cases be strictly better to estimate the low order model using reduction techniques, and in most cases we get the same variance as the direct estimation would have given. This result has also been published in [18]. The output error case is treated in [59].The main results from this analysis are a covariance expression for the final low order model that is easy to compute and an analysis on how to optimize this approach with respect to variance.

In the case of undermodeling, the variance can also be estimated using a bootstrap technique, [11]

3.3 Subspace selection techniques for classification problems

The main topic of David Lindgren's licentiate thesis, [7] is to find low dimensional projections of observed data that makes classification and clustering more efficient.

Three new algorithms are introduced and described. The *Asymmetric Class Projection* is a computationally efficient method to find subspaces for classification between two classes with small mean and large covariance differences. The *Optimal Discriminative Projection* (ODP) is an algorithm that uses a particular composition of Givens rotations to parameterize all subspaces. The subspaces are optimized for classification. The *Clustered Regression Analysis* uses the ODP subspace for conditional expectation prediction.

These results are also presented in [22].

3.4 Simple process models

In process industry models of type deadtime + dominating time constant + static gain are commonly used:

$$G(s) = \frac{K}{1 + sT_{p1}} e^{-sT_d} \tag{3.1}$$

Among variants of this model, we can have a model without delay ($T_d = 0$):

$$G(s) = \frac{K}{1 + sT_{p1}} \tag{3.2}$$

and/or introduce an enforced integration (self-regulating process)

$$G(s) = \frac{K}{s(1 + sT_{p1})} e^{-sT_d} \tag{3.3}$$

Moreover, on can postulate two real poles with or without a zero

$$G(s) = \frac{K(1 + sT_z)}{(1 + sT_{p1})(1 + sT_{p2})} e^{-sT_d} \tag{3.4}$$

A further possibility is to allow resonant poles (”under-damped models”):

$$G(s) = \frac{K(1 + sT_z)}{1 + 2\zeta sT_r + (sT_r)^2} \tag{3.5}$$

Clearly a variety of models can be defined based on these components.

It is interesting to study how such models can be estimated. Classical techniques involve graphical and similar methods. Of course, these simple process models can also be estimated within the traditional prediction error framework. Such issues are discussed in [68] and [34].

3.5 Determining model structures with ANOVA

Assume that a non-linear FIR model describes the measurements y_t from a system with input u_t, that is,

$$y_t = g(u_t, u_{t-T}, u_{t-2T}, ..., u_{t-kT}) + e_t.$$

The value of k is unknown in addition to which time lags of u_t that contributes to the value of y_t and g is an unknown static non-linear function of up to $k+1$ variables. If proper regressors could be found without too much effort, the problem of selecting the function g and estimate its parameters would be much easier.

The statistical analysis method ANOVA is a widely spread tool for finding out which factors contribute to given measurements. It has been used and discussed since the 1940’s and is a common tool in medicine and quality control applications. ANOVA has been applied to the problem above in an approach, novel to the system identification area [47]. The main advantage of the method is that *no assumptions on the function g are needed.*

The method is based on hypothesis tests with F-distributed test variables computed from the residual quadratic sum, where the residuals are the difference between the measured output and the output from a very coarse model based on sample means. Depending on what hypotheses are tested to be true or false a corresponding model structure can be obtained. This model structure defines the selected regressors and what relation they should have in the model, that is, if they affect the output additively or with interaction. Various aspects and properties of ANOVA in system identification applications have been discussed in [47].

3.6 Verification of Piecewise Affine Systems

Piecewise affine systems constitute an important subclass of hybrid systems, and consist of several affine dynamic subsystems, between which switchings occur at different occasions. As for hybrid systems in general, there has been a growing interest for piecewise affine systems in recent years, and they occur in many application areas.

In many cases, safety is an important issue, and there is a need for tools that prove that certain states are never reached, or that some states are reached in finite time. The process of proving these kinds of statements is called *verification*. Many verification tools for hybrid systems have emerged in the last ten years. They all depend on a model of the system, which will in practice be an approximation of the real system. Therefore it would be desirable to learn how large the model errors can be, before the verification is not valid anymore. In [62], a verification method for piecewise affine systems is presented, where bounds on the allowed model errors are given along with the verification. It is also suggested how this method can be combined with certain aspects of control design.

3.7 Models on Demand: Direct Weight Optimization

In this project, we focus on the identification of nonlinear models, and, in particular, on the situation that occurs when a very large amount of data is available.

Traditional treatments of the estimation problem in statistics and system identification have mainly focused on global modeling approaches, i.e., the model has been optimized on basis of the entire data set. However, when the number of observations grows very large, this approach becomes less attractive to deal with because of the difficulties in specifying model structure and the complexity of the associated optimization problem. Inspired by ideas from local modeling and database systems technology, we have taken a conceptually different point of view. We assume that all available data are stored in a database, and that models are built “on demand” as the actual need arises. When doing so, the bias/variance trade-off inherent to all modeling is optimized locally by adapting the number of data and their relative weighting. For this concept, the name *model-on-demand* has been adopted.

This concept is formalized as a direct optimization of weights in a linear-in-output observations estimate. The criterion to be optimized is the max mean square error over a certain family of functions. Results of this kind are given in [82], and [60].

3.8 Linear Approximations of Nonlinear Systems

In real life all systems are nonlinear. Yet, most models estimated using data from such systems are linear. It is very relevant to ask what linear approximation these models will converge to. A general answer can be given in terms of the cross spectrum between the input and the output and of the input spectrum (assuming these exist). A second order linear equivalent of the true system can be computed essentially using Wiener filter theory. The best approximation will depend on the input used.

It is an important but difficult problem to characterize, in general terms, this best model and how it differs from the true system. Some initial results along these lines are given in [41] and [57].

3.9 Other Aspects on Identification Methods

Approximation, Model Error Modeling and Control Design

Much of recent research is dedicated to understand the two main uncertainty sources, leading to model errors: unmodeled dynamics and noise affecting the data. In [10], we discuss and compare three approaches to System Identification, that explicitly aim at separating these contributions: Goodwin's Stochastic Embedding, Model Error Modeling (employing prediction error methods) and Set Membership Identification. An example, using (simulated) data from a non-linear plant, illustrates the methods.

Accelerated Convergence in Stochastic Approximation

It is well known that the simple LMS (gradient) method for estimating the parameters of a linear regression could be quite slow:

$$\hat{\theta}(t) = \hat{\theta}(t-1) + \gamma(t)(y(t) - \varphi^T(t)\hat{\theta}(t-1)) \tag{3.6}$$

It has been known for a while that the asymptotic properties of this estimate can be improved towards the theoretic Cramer-Rao limit by a second round of averaging of $\hat{\theta}(t)$. Some new variants and aspects of this have been analyzed in [14] and [24].

Optimal Subspace Methods

So called *Subspace methods* have been the subject of considerable recent interest in the literature on System Identification. The methods are intriguing, since they are numerically efficient, fast and do not require iterative search. At the same time they contain several design variable choices, and there is no full understanding about the best choices of these. Some partial results along these lines are given in [8]. Some improvements in the algorithms are suggested in [48].

Initialization of parametric search in identification of linear systems

When we have a physically parameterized linear model, it is important question to find good initial parameter estimates, where to start the iterative search for the best parameters. Some ideas to deal with this problem are described in [31].

Local linear models

A model may have so called *regime variables* to characterize some operating point or similar. A model that is linear for fixed regime variables is called a *local linear model*. Techniques to estimate such models in state-space form are suggested in [15].

Chapter 4

Nonlinear Systems

4.1 Algebraic Methods in Control

Many problems in control theory can be formulated as formulas involving polynomial equations, inequalities, quantifiers ($\exists, \forall$) and logical connectivities ($\vee, \wedge$). One example of such a formula is

$$\exists\, u \ \left[f(x,u) = 0 \ \wedge \ u^2 \leq 1 \right].$$

This can be seen as a description of all points, $x \in R^n$ of a nonlinear system, $\dot{x} = f(x,u)$ which can be made stationary by use of some admissible control, $u^2 \leq 1$.

The problem of *Quantifier Elimination*, (QE) consists of finding a formula without quantified variables (without u in the above case) which is equivalent to the original formula. This is always possible according to a result in the late forties by A. Tarski. However, the calculations involved in this original algorithm was to complex to be of any practical value. Lately there has been an increasing interest in QE due to the rapid development of computer algebra.

The most efficient implementations of QE-algorithms today are based on *Cylindrical Algebraic Decompositions*, (CAD). The method constructs a decomposition of R^n such that a given set of polynomials have constant sign on each component. Such a decomposition is a starting point for the elimination of quantified variables from a formula.

Other system theoretic questions concern the elimination of variables, for instance in going from state space to input-output descriptions In [33] many of the aspects concerning the use of algebraic methods in control are described.

4.2 Lyapunov based design tools

4.2.1 Backstepping for rigid bodies and in flight control

Aircraft flight control design is traditionally based on linear control theory, due to the existing wealth of tools for linear design and analysis. However, in order to achieve tactical advantages, modern fighter aircraft strive towards performing maneuvers outside the region where the dynamics of flight are linear, and the need for nonlinear tools arises.

In this research project we investigate backstepping as a new framework for nonlinear flight control design. Backstepping is a recently developed design tool for constructing globally stabilizing control laws for a certain class of nonlinear dynamic systems.

We have also extended the control concept to include control of general rigid bodies, [55]. It tuns out to be possible to control the velocity of a rigid body, even if the force input is one-dimensional, provided the applied torque can be chosen arbitrarily in three-space.

4.3 Control allocation

Aircraft control allocation deals with the problem of distributing a given aerodynamic moment demand among an available, redundant set of control surfaces. Most existing methods for control allocation are static in the sense that the resulting control distribution only depends on the current moment demand. In [52, 53] a method for dynamic control allocation is proposed in which the relationship between the moment demand and the resulting control distribution is dynamic. This is achieved by penalizing the rates as well as the positions of the actuators. In the nonsaturated case, the resulting control distribution is determined by a first order linear filter which can be assigned different properties at different frequencies. The main advantage of the method is that it allows the user to design the transient and steady state control distributions separately.

The connection between control allocation and traditional linear quadratic theory is explored in [54].

The use of classical active set methods for real-time control allocation is investigated in [56]. It describes active set algorithms that always find the optimal control distribution, and shows by simulation that the computational complexity is in the same range as for approximate pseudoinverse methods, which have been previoulsy suggested by several researchers.

4.4 Model Predictive Control

In Model Predictive Control (MPC) an optimal control problem over a finite horizon is solved. To handle robustness and disturbance issues, minimax MPC has been studied. In particular the joint extimation and control problem has been investigated in [64]. The problem of uncertain input gain is considered in [65] while minimax MPC for LFT is treated in [66]. Finally some alternative approaches for minimax MPC are considered in [67].

4.5 DAE models and bond graphs

DAE (differential-algebraic equation) models extend ordinary state space models by allowing arbitrary equations containing the derivatives of physical variables implicitly as well as purely static relations. They are of interest in modeling mode changes in systems, because a mode change can introduce additional equations that destroy a state space structure. A switched bond graph approach to this problem is presented in [9]. An algorithm that gives initial values for the continuous state variables is derived from the switched bond graph representation of the system. It handles discontinuities introduced by a changed number of state variables at a mode change. The algorithm is obtained by integrating the bond graph relations over the mode change and assuming that the physical variables are bounded. This gives a relation between the variables before and after the mode change. It is proved that the equations for the new initial conditions are solvable.

The algorithm is related to singular perturbation theory by replacing the discontinuity by a fast continuous change. The action of a single switch tuned by a single parameter is considered. By letting this parameter tend to zero, the same initial state values are achieved as the ones derived by the presented algorithm. The algorithm is also related to physical principles like charge conservation.

Chapter 5

Sensor fusion

This project is carried out by Division of Communication Systems and Division of Automatic Control in cooperation with SAAB (Dynamics and Gripen) Volvo (Cars), and NIRA (Automotive algorithms). Highlights of the year are

- the survey paper [20], in IEEE Trans. on Signal Processing, which surveys six different applications involving collaboration with six different companies. This paper summarizes most activities below.

- The licentiate theses by Rickard Karlsson [2], Per-Johan Nordlund [3] and Niclas Persson [6].

- The increasing number of invited and regular conference papers [27, 50, 77, 78, 80].

The students in these area are summarized below:

Name	Company	Funding	Start	Lic.	PhD
Jan Palmqvist	SAAB Aircraft	ISIS	1995	1997	–
Niclas Bergman	–	ISIS	1996	1997	1999
Rickard Karlsson	formerly SAAB Dynamics	ISIS	2000	2002	–
Per-Johan Nordlund	SAAB Aircraft	ISIS	2000	2002	–
Jonas Jansson	Volvo Car	Volvo	1999	2001	–
Andreas Eidehall	Volvo Car	Volvo	2002	–	–
Christina Grönwall	FOI	FOI	1997	2000	–
Gustaf Hendeby	–	ISIS	2002	–	–

Jan Palmqvist became manager of the navigation group at SAAB 1998, a position that Per-Johan Nordlund was offered 2002. Niclas Persson became a project leader at NIRA Dynamics 2002. Niclas Bergman is now at SAAB CelsiusTech and he is responsible for data fusion within the SAAB concern.

5.1 Particle filter

The particle filter has become central for most of the sensor fusion application, so we start with a brief overview.

Traditionally, linear or linearized models are used, where the uncertainty in the sensor and motion models is typically modeled by Gaussian densities. Hence, classical sub-optimal Bayesian methods based on Kalman filters can be used. The sequential Monte Carlo method, or particle filter, provides an approximative solution to the non-linear and non-Gaussian estimation problem. The particle filter approximates the optimal solution, hence it can outperform the Kalman filter in many cases, given sufficient computational resources.

Let $x_t \in \mathbb{R}^n$ denote the state of the observed system and $\mathbb{Y}_t = \{y_i\}_{i=1}^t$ be the set of observations until present time. Consider the following non-linear discrete-time tracking system

$$\begin{aligned} x_{t+1} &= f(x_t, v_t) \\ y_t &= h(x_t, e_t), \end{aligned}$$

with process noise v_t and measurement noise e_t. The process noise reflect the unknown target maneuver and the measurement noise the sensor errors. The non-linear prediction density $p(x_t|\mathbb{Y}_{t-1})$ and filtering density $p(x_t|\mathbb{Y}_t)$ for the Bayesian interference are given by

$$\begin{aligned} p(x_{t+1}|\mathbb{Y}_t) &= \int_{\mathbb{R}^n} p(x_{t+1}|x_t)p(x_t|\mathbb{Y}_t)dx_t \\ p(x_t|\mathbb{Y}_t) &= \frac{p(y_t|x_t)p(x_t|\mathbb{Y}_{t-1})}{p(y_t|\mathbb{Y}_{t-1})}. \end{aligned}$$

Sequential Monte Carlo methods, or particle filters, provide an approximative Bayesian solution to discrete-time recursive problem by updating an approximative description of the posterior filtering density.

The Monte Carlo filter approximates the probability density $p(x_t|\mathbb{Y}_t)$ by a large set of N particles $\{x_t^{(i)}\}_{i=1}^N$, where each particle has an assigned relative weight, $w_t^{(i)}$, such that all weights sum to unity. The location and weight of each particle reflect the value of the density in the region of the state space. The particle filter updates the particle location and the corresponding weights recursively with each new observation.

The posterior is estimated by a delta-Dirac sum using the importance weights

$$p(x_t|\mathbb{Y}_{t-1}) \approx \sum_{i=1}^{N} \tilde{w}_t^{(i)} \delta(x_t - x_t^{(i)}),$$

where $w_t^{(i)} \propto p(y_t|x_t^{(i)})$ and $\tilde{w}_t^{(i)}$ is the normalized weights. The recursive solution using particle filters may be implemented using the *sampling importance resampling* (SIR) algorithm from Gordon et. al. 1993.

In Figure 5.1 the particle filter method is demonstrated where the particles or samples are used to visualize the posterior.

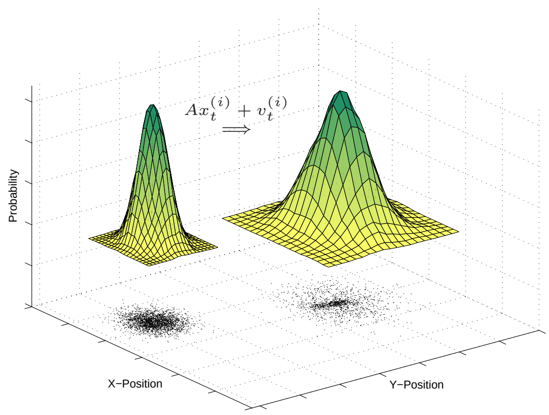

Figure 5.1: Probability density using the SIR method.

5.2 GIS based positioning

5.2.1 Aircraft terrain navigation

The research conducted in the area of sensor fusion has its origin in an application of terrain aided aircraft navigation. Since this application has been instrumental for the other activities, we start with a short review of this project.

In this application an aircraft position is autonomously determined by fusing measurements from an inertial navigation system, a digital map and a radar altimeter. By measuring the terrain height variations along the aircraft flight-path and comparing these with a digital terrain map, a position estimate of the aircraft is obtained. The comparison between the map and the measurements is a nonlinear estimation problem where unconventional and conceptually different sources of information are fused together. Research as been focused on finding a reliable and effective algorithm for this position determination.

During this work, close contact has been established both with Saab Dynamics and Saab Military Aircraft. A full-scale commercial implementation of a company secret solution has been developed at Saab during a period of two decades. Their expertise in this application field has proved extremely useful when developing and testing new ideas.

An effective algorithm solving the terrain-aided navigation problem has been developed and implemented. Simulation tests comparing the newly developed method with the full-scale implementation at Saab shows outstanding performance of the new method, both concerning the speed of convergence of the algorithm and the steady state estimation accuracy. The superior performance is obtained at a fairly low computational cost which allows for online implementation.

Furthermore, the terrain-aided navigation problem has been analyzed and fundamental bounds on the achievable performance have been derived. The implemented method developed in this work has been shown to meet these bounds in extensive simulation evaluations. The bounds have also been used to derive information maps which can be used to support mission planning.

More recently, work has been directed towards the general issue of on-line estimation for non-linear and non-Gaussian state space models. The experience from the terrain navigation application have been generalized and applied to the recursive estimation problem. Work has been conducted in the area of simulation based methods for nonlinear estimation. This is a currently very hot area which promise tractable solutions to high dimensional estimation problems. Algorithms for simulation based estimation in recursive estimation have been studied, and applied to the terrain navigation application. General bounds for nonlinear recursive estimation have also been developed. The project is presented in detail in:

- N. Bergman, *Recursive Bayesian Estimation: Navigation and Tracking Applications*, 1999.
- N. Bergman, L. Ljung and F. Gustafsson *Terrain Navigation using Bayesian Statistics* IEEE Control Systems Magazine 19(3), June 1999.

5.2.2 Aircraft integrated navigation

This project is currently focused on finding feasible estimation algorithms for integrated aircraft navigation. Integrated navigation means that measurements from two or more navigation sensors are fused to provide a more accurate and reliable navigation solution. The sensors we have been concentrating on are the inertial navigation system together with terrain-aided positioning. The challenge here consists of finding algorithms that solve the recursive Bayesian estimation problem for a system which is highly nonlinear (terrain-aided positioning) and at the same time is high-dimensional (inertial navigation).

This is an extension of the previous terrain-aided navigation project (see Section 5.2.1), which focused on horizontal position only. We know from this earlier project that recursive Monte Carlo methods, or particle filters, provide a promising solution to the two-dimensional terrain-aided positioning. However, increasing the dimension, including the entire spectra of states given by the inertial navigation system, makes the standard particle filter extremely ineffective. This calls for Rao-Blackwellization techniques, meaning that we marginalise the full conditional posterior density with respect to linear (or almost linear) parts, and estimate these parts using multiple Kalman filters. The remaining low-dimensional part of the state vector is estimated using the particle filter. For details on the Rao-Blackwellization method see [3].

5.2.3 Vehicle positioning

Map matching is used in all commercial automotive navigation systems. It normally simply means that the GPS position is mapped to the closest road on the map. We have extended that definition to *map a driven trajectory to a road map*. The particle filter provides an algorithm for computing the optimal mapping from double integrated wheel speed signals to the road map. That is, a GPS free positioning system is obtained, where the only sensors are wheel speed and a road map (interpreted as a state constraint).

Fig. 5.2 shows a sequence of images of the particle cloud on a flight image of the local area. The driven path consists of a number of 90 degrees turns. Initially, the particles are spread uniformly over all admissible positions, that is, on the roads, covering an area of about one square kilometer. After the first turns, a few clouds are left. After 4–5 turns, the filter essentially has converged. One can note that the state evolution on the straight path extends the cloud along the road to take into account unprecise velocity information. Details of the implementation are found in [80].

Figure 5.2: Car positioning: Sequence of illustrations of particle clouds (white dots) plotted on a flight image for visualization. The center point '+' shows the true position and 'x' the estimate.

The system has been implemented in a Compac IPAQ hand held computer by a master thesis project, and a complete car navigation system was developed as another student project.

5.2.4 Cellular phone positioning

The problem of position estimation from Time Difference Of Arrival (TDOA) measurements occurs in a range of applications from wireless communication networks to electronic warfare positioning. Correlation analysis of the transmitted signal to two receivers gives rise to one hyperbolic function. With more than two receivers, we can compute more hyperbolic functions, which ideally intersect in one unique point. With TDOA measurement uncertainty, we face a non-linear estimation problem. We here suggest and compare both a Monte Carlo based method for positioning and a gradient search algorithm using a non-linear least squares framework. The former has the feature to be easily extended to a dynamic framework where a motion model of the transmitter is included. The project is summarized in [27].

5.3 Target tracking

Many target tracking applications can be studied using a Bayesian formulation.

5.3.1 Angle-only tracking.

In Figure 5.4 an air-to-air passive ranging is presented. The passive ranging or angle-only tracking application, when only angle information is available has been investigated. In [2] an air-to-air application is studied where the particle filter is compared to a bank of linearized Kalman filters. Also the choice of coordinate system is discussed, where Cartesian and modified spherical systems are used.

5.3.2 Monte Carlo data association.

In [2] a multi-target data association application a simulation based approach for data association is proposed and compared to classical algorithms for an air-to-air tracking application. Moreover, the number of particles needed in the particle filter is adapted using a control structure to reduce the computational complexity.

Many target tracking applications can be studied using a Bayesian formulation.

5.3.3 Monte Carlo data association.

In [2] a multi-target data association application a simulation based approach for data association is proposed and compared to classical algorithms for an air-to-air tracking application. Moreover, the number of particles needed in the particle filter is adapted using a control structure to reduce the computational complexity.

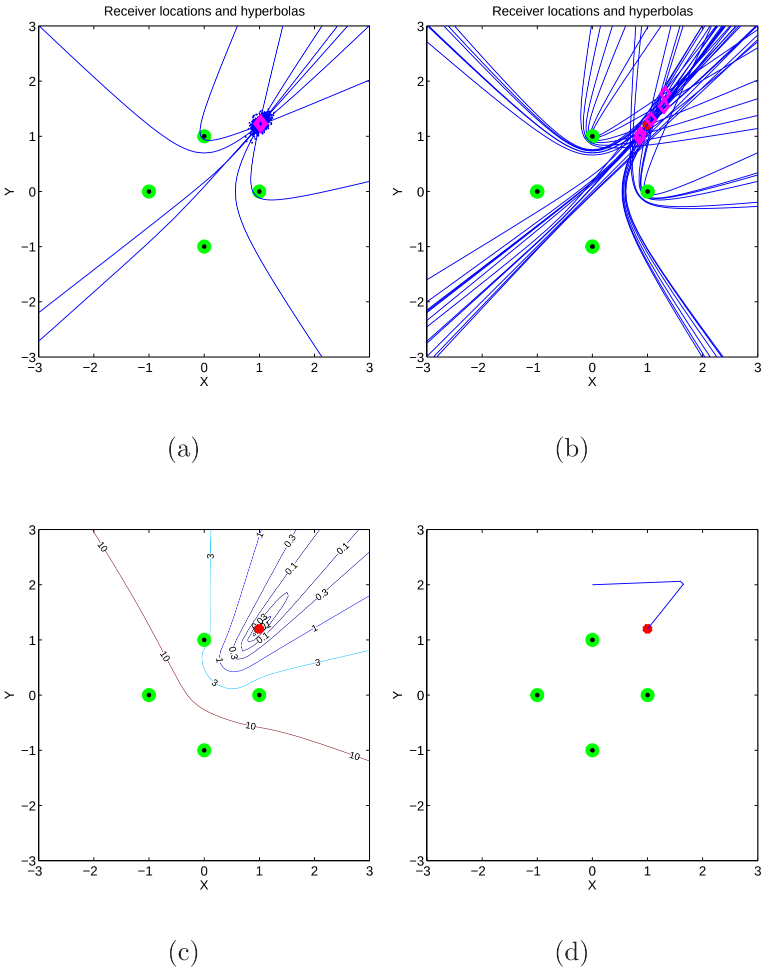

Figure 5.3: (a) Test scenario: four receivers are placed in a square, and six resulting hyperbolic functions from noise-free TDOA:s intersect at the transmitter position. Also shown is the particle cloud and the resulting position estimate using a proposed algorithm. (b) Same as (a), but the hyperbolic functions are computed from six different noisy TDOA vectors. This illustrates that in general there is no unique intersection of all six lines. (c) Contour plot of non-linear least squares criterion $\sum_{i<j}(\Delta d_{i,j} - h(X, Y))^2$. In this scenario, there is no local minima and a gradient algorithm will converge from any initialization. (d) Gradient search using a normalized least mean square method (compare the path to the contour plot in (c)).

Figure 5.4: Air to air passive ranging.

5.4 Forward Collision Avoidance of Cars

Looking at accident statistics one finds that the majority of accidents are caused or increased in severity by driver errors. The Indiana Tri-Level Study (Treat et al. 1979) found driver errors to be a cause or severity-increasing factor in 93% of the accidents. Furthermore 27% of all accidents (USA 1997) were frontal collisions where the struck vehicles were hit from behind (often called rear-end collisions). The traditional way of protecting the driver is to improve the vehicles passive safety i.e. body structural design, airbags etc. Todays sensor and signal processing technology allows us to create systems that can compensate for driver errors by means of for example warnings and/or brake-actuation. Forward looking systems will mainly affect frontal collision (which as indicated above is a major part of all collisions occurring). The purpose of forward collision avoidance systems is to avoid or mitigate collisions that occur in front of the vehicle carrying the system. There are many countermeasures that could be considered for this purpose. Examples of countermeasures are warning signals to the driver, braking interventions, steering interventions, pre tensioning of seat belt etc. The performance of the decision making algorithm is crucial i.e. ”faulty” interventions are not allowed (especially when one is considering active take over functions such as braking and steering interventions). Many algorithms suggest to use measures such as time to collision, relative speeds and distances for decision making. These measures although intuitively easy to understand, might be difficult to use for complex driving situations. The problem that has to be solved when constructing a collision avoidance system is to try to find laws or decision-making rules for when to deploy the collision avoidance countermeasure. The decision must be correct and robust in all types of traffic situations. There are two desired properties on a collision avoidance system:

1. Avoid all collisions

2. No faulty interventions are allowed. A collision avoidance system should not react except when it is really necessary to do so, otherwise it will be perceived as a nuisance to the user.

These two properties are in contradiction and the decision making algorithm has to be a good trade off between them. How this tradeoff should be done depends on several factors. One of the major factors is what type of countermeasure will be used.

In this project, a framework for how to deal with risk estimation and decision making for general driving situations are presented. Specifically we discuss how to deal with measurement uncertainties and driver behavior. We will in more detail discuss issues of autonomous braking actuation i.e Collision Mitigation by Braking (CMBB). We will also discuss the best possible performance that can be achieved by a CMBB system and what performance to expect when using commercially available sensors. Performance of a system using the proposed method will be exemplified with simulation results as well as results from test drives with a demonstrator car equipped with a collision mitigation by braking system.

The research is documented in a patent application, one SAE paper [77] and one IFAC World Congress paper [78].

Figure 5.5: The CMBB system is evaluated in a Volvo V70 in collisions with the inflatable car on the picture.

5.5 Performance analysis of laser radar systems

This project concerns performance analysis of estimation algorithms based on data from a generic laser radar system. A tool in this work is modelling of different kinds of laser radar systems and the kind of data that they produce. The measurement system (i.e., laser radar system) model contains several design parameters, which makes it possible to test an estimation scheme under different types of system design. The measurement system model includes laser characteristics, object geometry, reflection, speckles, atmospheric attenuation, turbulence and a direct detection receiver. Thus, the data generation is based on sound calculations of physical properties. Data is analyzed by a general, parametric least squares method. There are measurement errors present and therefore the parameter estimation is based on a measurement error model. The parameter estimation accuracy is limited by the Cramer-Rao lower bound (CRLB). Our goal with this work is to connect the design parameters of a measurement system with a parametric description of an object. This gives us a tool to evaluate the effects of the measurement system's design parameters on the result of the recognition algorithm.

In [73] we show the connection between the CRLB expression of a parameter in the estimation method (θ) and the scan angle of the laser radar system (α). After some calculations, see [73], we retrieve the CRLB as a function of number of samples, measurement distance, $\hat{R}$, and angle, α, uncertainties in measurement distance and angle and the parameter estimated by the least squares method, θ. A numerical illustration is shown in Figure 5.7, in this case we have no bias.

5.6 Tire Pressure Monitoring

Event based sampling occurs when the time instants are measured everytime the amplitude passes certain pre-defined levels. This is in contrast with classical signal processing where the amplitude is measured at regular time intervals. The signal processing problem is to separate the signal component from noise in both amplitude and time domains. Event based sampling occurs in a variety of applications. The purpose here is to explain the new types of signal processing problems that occur, and identify the need for processing in both the time and event domains. We focus on rotating axles, where

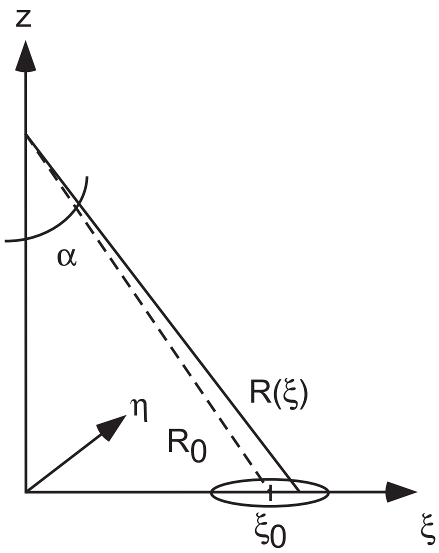

Figure 5.6: The geometry of a pulse response when the η axis is ignored. α corresponds to the scan angle. The slant range $\hat{R}$ is an estimate of R_0.

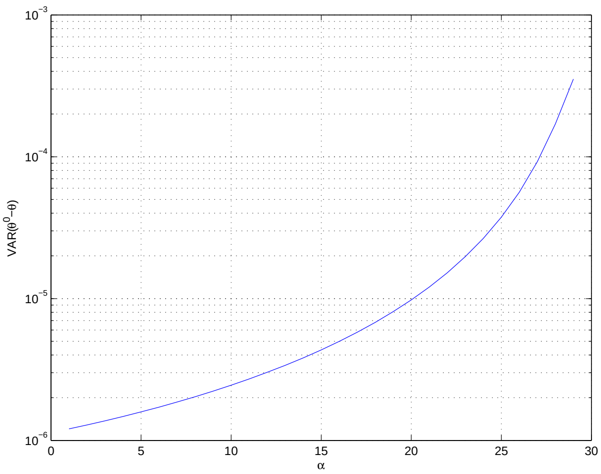

Figure 5.7: CRLB as a function of scan angle α. The variance in the estimate of θ increases when α increases. In this case we have no bias.

amplitude disturbances are caused by vibrations and time disturbances from measurement equipment. As one application, we examine tire pressure monitoring in cars where suppression of time disturbance is of utmost importance. The project is described in the licentiate thesis [6] and the SAE paper [50].

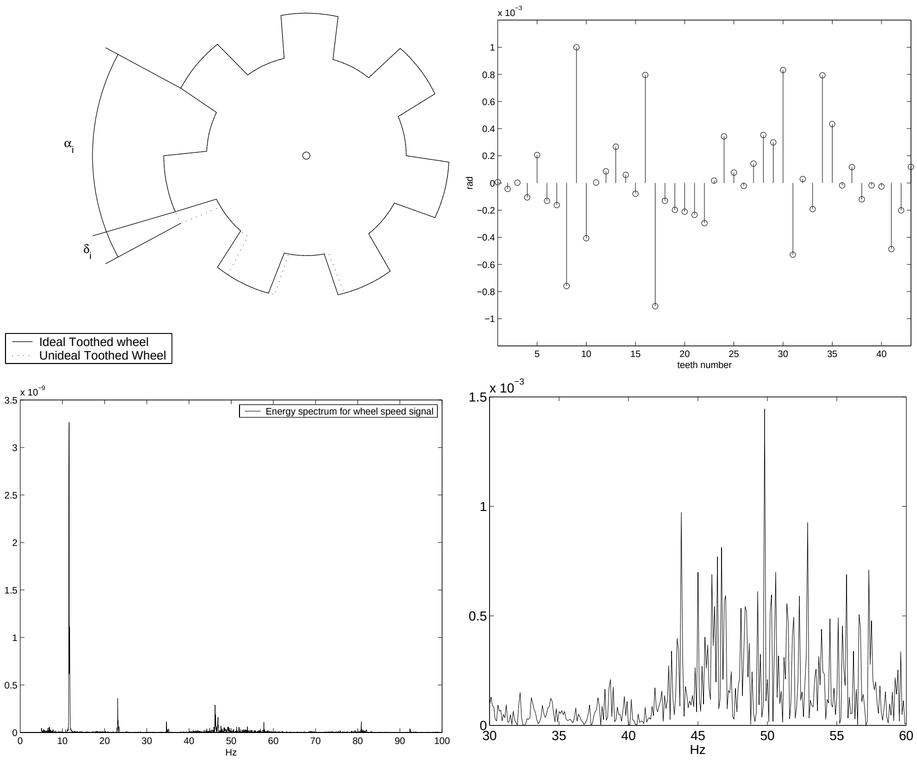

Figure 5.8: First plot: The toothed wheel measured the time for events, where the measurements are the times to come to angle (event based sampling) $t[k] = t(k\Delta_y), \quad k = 1, 2, \ldots, N_t$ rather than the angle at a specified time (equidistant sampling) $y[k] = y(k\Delta_t), \quad k = 1, 2, \ldots, N_y$. Second plot: the angles are however not perfectly symmetric, and the plot shows the estimated angular error. Third plot: without estimation of the angular errors, the estimated signal spectra is dominated by these disturbances. Fourth plot: with compensation of angular errors, the spectra reveals in the information of the resonance around 45 Hertz which is significant for tire pressure monitoring.

Chapter 6

Detection and Diagnosis

6.1 Fault Isolation in Control Systems with Object Oriented Architecture

6.1.1 Introduction

Developing control systems for complex systems is a difficult and increasingly important task. Large control systems have traditionally been developed using structured analysis and functional decomposition. Today, many large systems are designed using an object oriented approach. This has several advantages over traditional approaches, including better possibility to cope with complexity and to facilitate maintenance and reuse. It leads to new kinds of problems, though, and we concern ourselves with the problem of fault propagation caused by an object oriented software architecture. As basic inspiration and case study we have used a commercial control system for industrial robots developed by ABB Robotics; the system is highly configurable, programmable and has an object oriented architecture. More work on industrial robots is described in Chapter 8.

Object-oriented design goals such as *encapsulation* and *modularity* often stand in direct conflict with the need to generate concise information about a fault situation, and to avoid propagating error messages. Error messages are sent by individual objects to notify, e.g., an operator that an error condition has been detected. The aim to encapsulate information implies that individual objects, or groups of objects, in general do not know how close they are to the fault or if the fault has already been adequately reported by another part of the system. When a fault situation occurs, e.g, a hardware component failure, a broken communication link or a real-time fault, it is not a very desirable system behavior to present a multitude of error messages from different parts of the system to an operator. For the operator, who normally has no insight in the internal design of the control system, it can be very difficult to understand which error message that is most relevant and closest to the real fault. For objects that are close to each other it is possible to suppress error messages by information passing, but this is not always feasible.

There are two main objectives of our work: On the one hand we want to devise a method that can be used for operator support. The aim is then to single out the error message that explains the actual cause of the failure, or possibly an unobservable critical event explaining the observations. We aim to discard error messages which are definitely effects of other error messages, while trying to *isolate* error messages (or critical events) which explain all other messages. That is, we propose a fault handling scheme as an extra layer between the operator and the core control system, performing post-processing of the fault information from the system to achieve clear and concise fault information to the operator, without violating encapsulation and modularity. On the other hand, our method can also be used at design time. At the design level, we want to find out, at design-time, if the error log design is sufficient, that is, if enough error messages are produced to be able to isolate all faults.

The fault isolation is done in two steps. In the first phase a structural model fault isolation is done, and in a second phase a behavioral model fault isolation is used only if needed. If the structural model fault isolation is successful in finding a single cause of all the error messages, the second phase of behavioral model fault isolation is not needed.

The structural model is represented mainly by the class diagrams in UML (unified Modeling Language). The main advantage with using a software engineering model is that it can be developed and maintained at a relatively low cost as it is an integrated part of the software development process. From the error messages in the error log we can find the cause-effect relation between the error messages. If there is no unique maximal element initially, we use the UML model, in particular the class diagrams, to extend the original graph. A prototype implementation of the structural approach has been made and tested on the ABB Robotics industrial robot control system.

6.1.2 Behavioral fault isolation

Since the structural model thus is an abstraction of all possible behaviors, it is not unlikely to have circular dependencies in the structural model without ever having circular dependencies in any specific scenario. When such a circular dependency occurs in the explanation graph the structural model is not sufficient to perform successful fault isolation, but having a behavioral model of the objects involved in the cycle we may be able to break the cycle. A dependency in the structural model, say class A depends on class B, means that there exists a scenario where an instance of class A depends on an instance of class B. It is not possible to deduce whether the dependency holds in the scenario at hand or not, since the model does not discriminate between different scenarios. By modeling also the behavior of the objects we get the opportunity to reason about dependencies that hold only under certain circumstances, i.e. in certain scenarios.

When starting behavioral model fault isolation we have a limited set of root candidates, i.e. events in the scenario that are suspected to have caused the failure of the system. This set is an output from the structural model fault isolation.

Our main focus lately has been to extend the structural approach to fault isolation using *behavioral methods* -more precisely we use UML state machines as notation for the behavioral model- and class instances rather than classes. We use the concept of *strong root candidate*. A strong root candidate is an event that is known to have occurred, and there is a run (consistent with the log) where this event is the first critical event.

We propose an approach to fault isolation based on *model checking* to locate strong root candidates (if they exist!)[42, 44, 111]. The property of being a strong root candidate is then expressed in the temporal logic CTL (normally used for verification). And we use an existing model checker to single out the strong root candidates.

6.2 Fault detection and diagnosis in process control systems

This project is carried out by in cooperation with ABB Automation Systems and ABB Corporate Research. The aim is to study and develop methods for detection and diagnosis in process control applications.

This project focuses on fault detection and diagnosis in pulp and paper processes. Typical characteristics of these systems are that they are large systems with a large number of signals/sensors, and the physical models are of limited accuracy.

We investigate how to make a model of a system with a large number of signals, where furthermore only a small part of the signal space contains data under normal operations. PCA, principal component analysis is a promising method for this, where singular value decomposition is used to find the relevant parts of the signal space. The PCA model can then be used to compare measured process output with model output, and compute a test statistic, which will differ from zero when a fault has occurred.

Once a fault is detected, the next step in the fault detection and diagnosis is to find the faulty sensor. Using a probabilistic approach we can minimize the misclassification.

PCA has usually been employed for static systems, and for certain sampling rates, the pulp and paper process can be regarded as such. It is however also interesting to include dynamic information into the model, i.e., by including delayed versions of the signals in the regressor. This is known as dynamic PCA, dPCA, and closely related to subspace methods.

6.3 Fault identifiability of additive faults in linear systems

The parity space approach to fault detection is an elegant and general tool for additive faults in linear systems and is based on intuitively simple algebraic projections and geometry. It provides a tool to compute a residual vector that is zero when there is no fault in the system and reacts to different faults in different patterns, enabling a simple algorithm for diagnosis (deciding which fault actually occurred). Examples on simulated data often show very good results. Consider for instance Figure 6.1, where a DC motor is subject to first an offset in control input and then an offset in velocity sensor.

The upper plot shows how structured parity space residuals correctly point out which fault has occurred. A main drawback is that the approach does not take measurement errors and state noise into consideration as in the classical Kalman filter literature. The lower plot in Figure 6.1 illustrates the high sensitivity to even quite a small measurement noise.

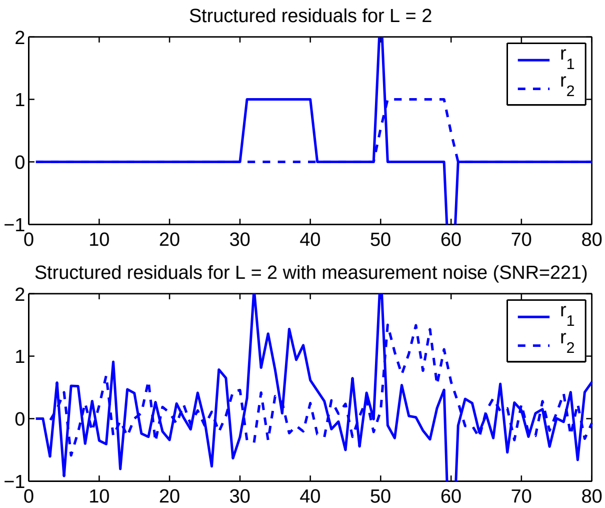

Figure 6.1: Parity space residual for a DC motor, as described in Section **??**, subject to first a input voltage offset and then a sensor offset. The two residuals are designed to be non-zero for only one fault each. The lower plot illustrates extremely high sensitivity in residuals to measurement noise (SNR=221).

We here mix the linear state space models used in fault detection and Kalman filtering, treating deterministic and stochastic disturbances in different ways.

In the paper [75], an explicit expression for $P^{i,j} = P(\text{diagnosis } j | \text{ fault } i)$ is given for any parity space, and the parity space is optimally designed to minimize these probabilities in order to improve sensitivity issues in diagnosis. The approach relies on spatial *and* temporal whitening of the parity space residuals. Practically, this means that each fault is mapped a mean residual vector, and the stochastic contribution to the residual is independent of the fault and adds to the residual as white noise with unit covariance matrix. Figure 6.2 illustrates the principle for a sampled DC motor.

The normalization enables a simple characterization for the decision regions for each fault isolation (straight lines in the residual space), and more importantly a tool to compute the probability for incorrect fault isolation, *without resorting to Monte Carlo simulations*. Figure 6.3 illustrates how one design parameter in the parity space approach (the sliding window size) affects this probability. Other applications are sensor localization and quality

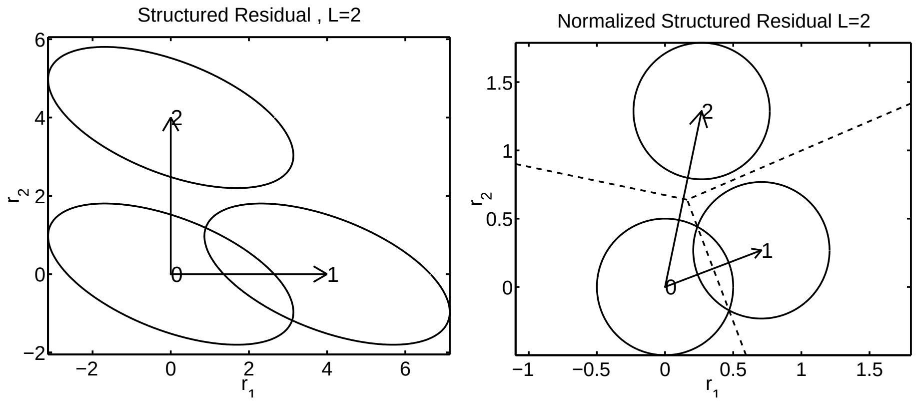

Figure 6.2: Original and normalized structured residual fault pattern with uncertainty ellipsoids for fault 1 and 2, respectively. Solid line is for unnormalized residuals, and dashed line after normalization. The dashed line is the optimal decision region.

specification, system design and so on.

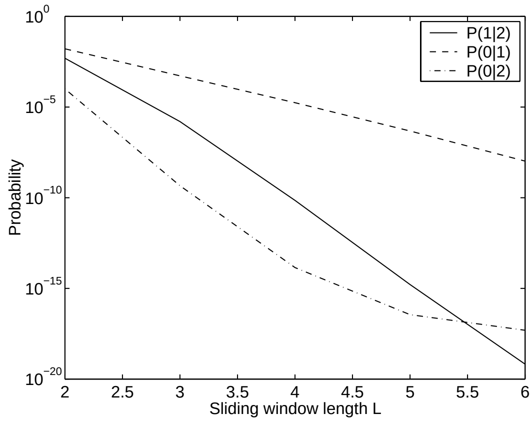

Figure 6.3: Miss-classification probabilities in diagnosis as a function of sliding window length.

Chapter 7

Communication Applications

7.1 Introduction

The global communications system today (the telephone system yesterday) is considered as the largest man-made system all categories. Due to the dramatic increase in number of users and their demand for more advanced services, the available resources have to be utilized efficiently. This is especially critical in the subset of wireless cellular communications systems, and in applications which require specific real-time behavior. The four projects are rather independent, but can to some extent all be related to the exemplifying wireless network in Figure 7.1.

Signal Processing for Analog to Digital Converters (ADC) With adequate signal processing, it is possible to significantly improve analog to digital converters. This is important for cheaper and more accurate radio receivers and to effectivice the individual links.

Power Control in Cellular Radio Systems Power control is an important means to compensate for variations in propagation conditions and interference and to utilize the radio resources efficiently. Thereby, sufficient power is used by each transmitter to maintain an acceptable quality of service, while not disturbing other connections unnecessarily much. Both control design and analysis aspects are considered of such distributed algorithms.

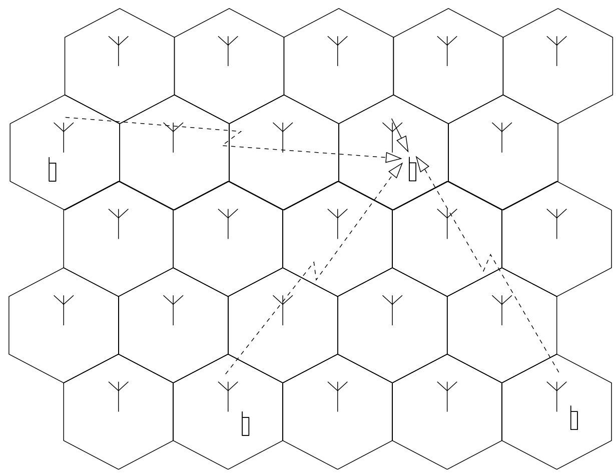

Figure 7.1: Downlink communications in a wireless network. The received signal at the mobile station consists of the desired signal (solid), interfering signals from other base stations (dashed) and thermal noise.

Uplink Load Estimation and Management Power control is not an efficient means for resource utilization if the system is overloaded. Therefore, it is important to manage the system load. Uplink load estimation is central due to the limited availability of accurate measurements. Furthermore, admission, congestion and other resource control are important tools to prevent the system from becoming overloaded.

Control, Fault Detection and Estimation in Data Networks Traffic flow control is well established in data communications. With mobile Internet becoming increasingly popular, it is important to consider these algorithms while cater for efficient utilization of the wireless links. Considered performance aspects are similar when discussing solely wired communications.

7.2 Signal Processing for Analog to Digital Converters (ADC)

Much of the physical space and power consumption in modern communication systems such as ADSL modems, cellular phones and radio base stations are due to the radio frequency signal processing. A very fast A/D converter could, in principle, be put directly to the antenna or at least closer to the antenna than today, and much more of the signal processing could be performed in software. This requires A/D converters with very high linearity to distinguish a weak signal from the harmonics from stronger signals.

7.2.1 Blind Equalization of Static Errors in SA-ADC and pipelined ADC

For fast high performance A/D conversion, pipelined or subranged successive approximation A/D converters (SA-ADC) are the best options. These A/D converters consist basically of a resistance ladder, where the voltage level between the resistances gives the digital reference levels. The correct digital level is found by comparing the analog input signal to these reference voltages, by binary search. Using only one resistance ladder, 2^N resistances are required to achieve N bits precision in the ADC. Pipelining or subranging is used to avoid too long resistance ladders. For these types of ADCs the comparison is split into two or more resistance ladders. The most significant bits are found from the first resistance ladder. When the correct level is found in the first ladder, another resistance ladder is fit into the correct interval in the first ladder, where the search is continued and less significant bits are found. In Figure 7.2 an example of a two stage subranging SA-ADC is shown. To

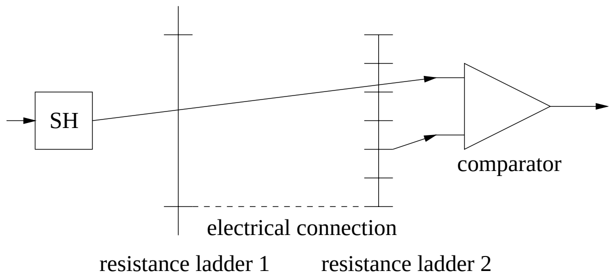

Figure 7.2: Two stage subranging SA-ADC. The conversion is done in two steps with two resistance ladders.

keep the power consumption and price at low levels, CMOS technology is used. One major problem is manufacturing errors leading to large uncertainties in the components. Due to errors in the resistances the distance between different reference levels in the resistance ladder are different, which means that the nominal digital reference levels do not correspond to the actual levels in the A/D converter. If the correct levels are known, these can be used to construct the digital signal instead of the nominal, equally spaced, reference levels. Here we have developed a patented method to adaptively and blindly compensate for the distortion with an algorithm suitable for implementation on the chip. We need only a spatial smoothness assumption on the input signal for this algorithm to work.

7.2.2 Adaptive Estimation of Amplitude, Gain and Timing Offsets in Parallel ADC's

One way of improving the speed of A/D conversion is to put M A/D converters in parallel. All the A/D converters have the same input signal but the clock signal is delayed with iT/M, where T is the sampling interval of one ADC. The outputs are then multiplexed to one signal with M times higher sample rate than the separate ADCs, see Figure 7.3. Due to this parallel,

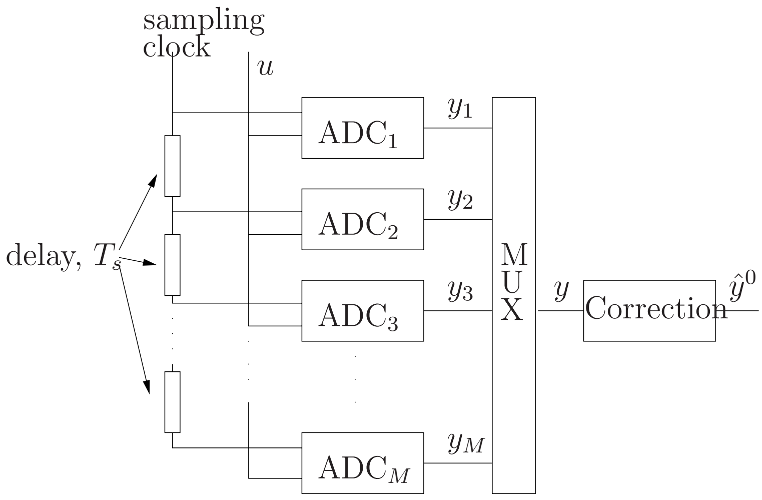

Figure 7.3: M parallel ADCs with the same master clock.

time interleaved setup, three types of errors occur:

- **Time errors (static jitter)**
  The delay time of the clock to the different A/D converters is not equal.

This means that the signal will be periodically but non-uniformly sampled.

- **Amplitude offset errors**
  The ground level can be slightly different in the different A/D converters. This means that there is a constant amplitude offset in each A/D converter.

- **Gain error**
  The gain, from analog input to digital output, can be different for the different A/D converters.

Here it is of utmost importance to compensate for gain, amplitude and time offsets, otherwise fake components in the frequency spectrum will appear. Here a patented blind adaptive algorithm for estimation of time errors has been developed. The algorithm requires no information about the input signal, except temporal smoothness. The method is analyzed in [45]. The algorithm has also been evaluated on measurements from a dual A/D converter system [46].

7.2.3 Randomly interleaved ADCs

Another way to decrease the impact of mismatch errors in time interleaved ADCs is to randomize the selection order of the ADCs. By doing this the mismatch errors give a more noise-like shape in the output spectrum. This means that the SFDR is improved while the SNDR is the same. A statistical model for this type of system has been developed. This model has also been compared to measurements from a real randomly interleaved ADC system.

Jonas Elbornsson and Fredrik Gustafsson are working in this project, see also the project description.

7.3 Power Control in Cellular Radio Systems

When a user is requesting a service from the cellular system, a radio link has to be established. First the appropriate base station to connect to is determined. The requested service corresponds to a specific data rate, and therefore a channel that can provided this data rate is allocated. Most things in the system are time-varying: mobiles move, users come and go, propagation condition varies etc. Closed-loop transmission power control is widely discussed as a means to compensate for the variations.

Since several connections are using the same channel, a signal intended for a certain user will reach other users as well, see Figure 7.1. This creates mutual interfering signals between the users and limit the performance.

For practical reasons, the powers have to be computed locally for each connection using local feedback, though performance and stability depend on how the different connections interact. We consider the power control problem as a decentralized control system, consisting of interconnected local control loops. Each connection controls the powers to obtain a sufficient *signal-to-interference ratio (SIR)* γ, which is the useful received power C divided by the harmful power, or interference power I (including thermal noise). In dB, SIR $\gamma_{dB} = C_{dB} - I_{dB}$. The reference values, typically referred to as target SIR:s, are denoted by γ^t. Hence, the challenge is to locally control the transmission powers using feedback of the control error $\gamma^t - \gamma_{dB}(t)$ to maintain an acceptable perceived connection quality.

Properties like stability and convergence are typical global properties related to the overall wireless network with mutual interference between the connections. While it is desirable to design and use the controllers locally, global stability results also have to be provided. It is easy to conclude that local stability is a necessary but not sufficient condition for global stability of the power control problem.

By analyzing power control from a control theory perspective, the following limitations are important:

- Not every user requirements can be supported by the system in terms of data rate.
- In practical cases the power can only be controlled based on local measurements and estimates.
- Measuring, estimation and control signaling takes time, which result in time delays in the system. Essentially, there is a trade-off between estimation accuracy and the presence of time delays.
- The measurements and/or control signals have to be transmitted over the radio interface. Since the available radio resources are limited, so is the feedback bandwidth. Moreover, the feedback channel may be subject to signaling errors resulting in feedback errors.

- The output power levels are limited to a given set of values due to hardware constraints. This includes quantization and saturation.

- The ability to mitigate time-varying disturbances are most naturally discussed in the frequency domain. An interesting issue is to address the performance in terms of the disturbance rejection bandwidth.

- Quality of Service is a very subjective quantity, and the choice of adequate quality measures is an important issue.

- Even if the optimal quality measure is found, this will most likely not be possible to measure. Thus it is important to extract as much relevant information from the available measurements.

These aspects are further discussed in the survey article [20].

Fredrik Gunnarsson is working on the project, which is a collaboration with Ericsson Radio Systems, Linköping and Kista.

7.4 Uplink Load Estimation and Management

When operating a cellular radio system at nearly full capacity, admitting yet another user may jeopardize the stability of the system as well as the performance of the individual users. Therefore, proper radio resource management is crucial. It is natural to base such management on a measure of the current load situation. This project aims at methods for estimating and managing the uplink load.

Prior art includes measures related to absolute number of users served by the base station and measures of the total received power at the base station I_j^{tot}. Both show promising results, but the former is difficult to configure, and the latter is based on a quantity, which is hard to measure accurately. Instead, the relative load of a base station is defined by

$$L_j = 1 - \frac{N_j}{I_j^{tot}} \Longleftrightarrow I_j^{tot} = \frac{N_j}{1 - L_j} \tag{7.1}$$

where N_j is the thermal noise power. Clearly, the relative load $L_j = 0$ corresponds to an unloaded base station (the received power is only thermal noise). Furthermore $L_j = 1$ constitutes an upper limit since it corresponds to an infinite received power. The proposed uplink relative load estimate [26, 40] is focused on WCDMA. It utilizes measurements readily available in that system, either periodically scheduled or from handover events. Initially, it is utilized in admission control, and it is easy to configure, and provides the possibility to predict the uplink load given that a specific user would be admitted in the system.

Furthermore, multi-services are naturally handled, and availability of high data-rate services are automatically limited with respect to coverage, compared to services of lower data-rate. This is illustrated by Figure 7.4, where the 192 kbps service is only available relatively close to the base stations (where users have higher power gains), while the speech service is available essentially everywhere.

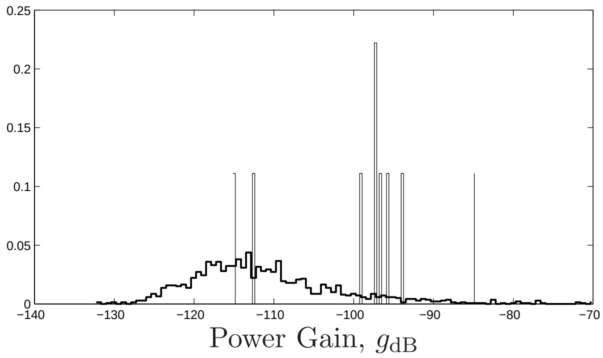

Figure 7.4: Histograms of power gains for admitted users with the services: 12.2 kbps (thick line) and 192 kbps (thin line).

Erik Geijer Lundin, Fredrik Gunnarsson and Fredrik Gustafsson are working in this project, which is an ISIS project in cooperation with Ericsson Research.

7.5 Control, Fault Detection and Estimation in Data Networks

The core problem is that the standardized flow control implementations used in data networks are not designed for the traffic situations of today, and that it is next to impossible to upgrade the software in all Internet routers. However, some networks are redesigned, and IP is used in new and closed environments, such as transport networks between base stations in cellular radio systems. Therefore, it is plausible to discuss alternative traffic control algorithms and protocols. Furthermore, not only the data flow of each user is controlled, but also the total flows through each router to prevent overload situations. The total system can hence be seen as a complicated distributed control system with complex inter-connections between the control algorithms.

The main flow control protocol on the Internet is TCP. A protocol is a set of rules that organizes a part of the traffic and TCP organizes the send rate and the sequence of data. Using an addition to the data packets TCP can keep track of the correct order of the packets and also notice if a packets are lost. This information gives an indication about the capacity of the network and TCP keeps an internal estimate of this capacity. The estimate is increased when a packet is delivered successfully and decreased if the packets is lost. The way of increasing and decreasing was standardized at the birth of the Internet and therefore TCP is not so well suited for todays traffic scenario.

An investigation of the performance of TCP has been done in [63, 72], where the occupation of the queue is used as the primary performance measure. Here a simulation model developed using simulink and stateflow is used, as well as the more complex network simulator developed at Berkeley, *ns-2*. A small *ns-2* simulation scenario is depicted in Figure 7.5.

Until now mainly heuristic methods have been used in the communication world to tune parameters and choose algorithms. There is a need for models that fit into existing frameworks such as control theory, probability theory and optimization theory.

Current work is developing a model of the network load when using TCP traffic and use this to find a good controller of the load. The aim is to use known control theory concepts and techniques. An investigation is carried out concerning performance measures and adaptive queue management techniques for this purpose.

Frida Gunnarsson, Fredrik Gunnarsson and Fredrik Gustafsson are working in this project.

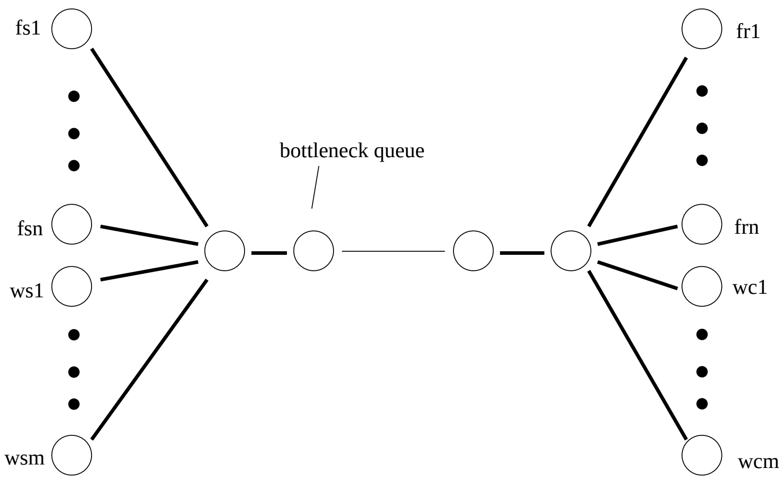

Figure 7.5: A *ns-2* simulation scenario with n file senders, fsi, with corresponding file receivers, fri, and m web servers, wsi, with corresponding web clients, wci.

Chapter 8

Robotic Applications

8.1 Introduction

This work is to a large extent carried out in cooperation with ABB Robotics within the competence center ISIS (Information Systems for Industrial Control and Supervision). The overall aim of the work is to study and develop methods for improvement of the performance of robot control systems.

8.2 Iterative Learning Control

Iterative learning control (ILC) has been an active field of research since the mid 80's. The method uses the fact that if a systems perform the same action repeatedly and has a deterministic behavior the error will also contain a component that is repeated. By using the error from previous "iterations" of the same action the error can be reduced. The structure of the problem is shown in Figure 8.1 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 an input to the controlled system and e_k is a measure of the control error. Q and L are operators that can be chosen by the user.

One important aspect that has been covered in 2002 is the effect of disturbances on a system controlled with an ILC algorithm. This is covered in [21], [23], and [16]. The contribution of [21] is to show how introducing a high-order ILC scheme according to

$$\begin{aligned} u_{k+1}(t) = H_{u,1}u_k(t) + \ldots + H_{u,N}u_{k-N+1}(t) \\ + H_{e,1}e_k(t) + \ldots + H_{e,N}e_{k-N+1}(t) \end{aligned} \tag{8.1}$$

can affect the disturbance rejection properties. In [23] and [16] iteration varying filters in the update equation of the ILC algorithm is covered. The convergence properties in time and frequency domain for linear systems is covered in [19]. For non-linear systems some new results are presented in [38]. An example where ILC is applied to a non-linear non-minimum phase system is discussed and the design aspects are highlighted.

One approach to ILC that has given an increased attention during the last few years is the Current Iteration Tracking Error (CITE) ILC. This approach uses an updating equation according to

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

that is a feedback loop in combination with an iterative update of the ILC input. In [36] frequency domain conditions for the convergence of CITE ILC algorithms are presented. A Bode's integral theorem interpretation of the convergence result is given and the restriction on the learning operators to be causal is highlighted.

Experimental evidence of the ILC algorithms are presented in [16] and in [17]. In [17] many different ILC algorithms are discussed and evaluated in an experimental environment using an ABB IRB1400 industrial robot manipulator.

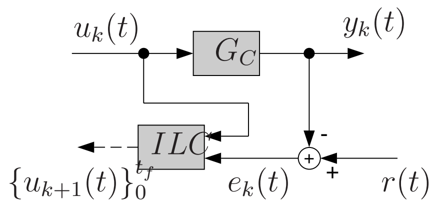

Figure 8.1: An example of a system controlled using ILC.

8.3 Robot Identification and Diagnosis

For both control and diagnosis of industrial robots it is important to have good mathematical models describing the properties of the robot. This problem has been considered in [4], [35], and [39] from different viewpoints.

In [4] and [39] it is discussed how a software tool, in this case Modelica, for physical modeling can be used for generating a suitable model structure that can be used for identification. An example is given in Figure 8.2, which shows a three-mass model used to describe the properties of a robot when moving around axis one. For an example of this size the state space equations can easily be derived by hand, but if the complexity is increased by adding more masses it becomes tedious the handle the problem. In such a case a tool like Modelica is very useful. Examples of how this tool can be used for this task are shown in [4] and [39].

There are several methods available for diagnosis of industrial systems, and the methods that have been considered here are based on recursive estimation of physical parameters in an industrial robot. Also here the starting point has been the three-mass model shown in Figure 8.2. To be able to monitor physical parameters in real-time it is necessary to use a recursive identification algorithm. This problem is discussed in [4] and [35], where data collected from an ABB IRB1400 are used. Different diagnosis methods based on recursive estimates of some different physical parameters are compared and evaluated.

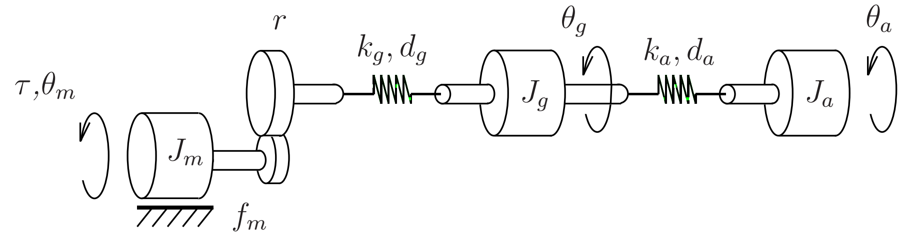

Figure 8.2: Three-mass flexible model.

Chapter 9

Optimization for Control and Signal Processing

9.1 Introduction

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

9.2 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 [28, 89] it is shown how to efficiently solve an optimal control problem with applications to model predictive control. The objective is quadratic and the constraints can be both linear and quadratic. The key to an efficient implementation is to rewrite the optimization problem as a second order cone program. This can be done in many different ways. However, done carefully, it is possible to use both very efficient scalings as well as Riccati recursions for computing the search directions.

9.3 Gain-Scheduling

Gain scheduling is a very powerful control methodology for systems with time varying parameters. The only requirement is that the process dynamics can be predicted. Often, analysis of a system controlled by a gain scheduled controller results in solving extremely large optimization problems involving linear matrix inequalities (LMIs) as constraints. Standard algorithms for solving these so called semidefinite programs (SDPs) cannot handle problems of the size commonly encountered in applications. However, the LMIs have a very special structure. If this structure is exploited and is combined with an interior-point method for solving the SDP a very efficient algorithm results, [29]

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), and an IFAC Advisor. He is also an IEEE Fellow 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), and from Uppsala University, Uppsala, Sweden (1998).
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Torkel Glad was 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 of Nonlinear Control systems in the department. His research interests include Nonlinear Systems, algebraic aspects of System Theory and Optimal Control.
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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. Since July 1996 he is Dean of the School of Engineering at Linköping University.
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Svante Gunnarsson was born in 1959. He received his M.Sc. in 1983, his Licentiate's degree 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 system identification and adaptive control.
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Fredrik Gustafsson was born in 1964. He received the M.S. degree in electrical engineering in 1988 and the Ph.D. degree in automatic control in 1992, both from Linköping University, Sweden. He is currently professor in Communication Systems at the Department of Electrical Engineering at Linköping University. His research is focused on statistical methods in system identification, signal processing and adaptive filtering, with applications to communication, avionic and automotive systems.
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Inger Klein is a associate professor at the department. She was born in 1964. She received her M.Sc. in 1987, her Licentiate's degree 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 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 is an associate professor at the Division of Automatic Control, Linköping University. His research interests are within the fields of optimal control, stochastic control, linear systems, signal processing, fuzzy logic, applications of control, image processing, and telecommunications.
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Kent Hartman was born in 1951. He received his M. Sc. in 1977 Applied Physics and Electrical Engineering at Linköping University, Department of Biomedical Engineering. He is an associate lecturer in the Control Group.
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Anders Helmersson 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 and is an adjunct professor at the Division of Automatic Control.
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Anna Hagenblad was born in Lycksele, Sweden, in 1971. 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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Mikael Norrlöf 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 as well as modeling, nonlinear control, trajectory generation, and identification of industrial robots.
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Fredrik Gunnarsson 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 work as a Senior Research Engineer at Ericsson Research.
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Fredrik Tjärnström was born in 1973. He received his M.Sc. Applied Physics and Electrical Engineering in 1997 and his Lic.Eng. in 2000 and his PhD in 2002 all at Linköping University. His research interests is uncertainty estimation of estimated models.
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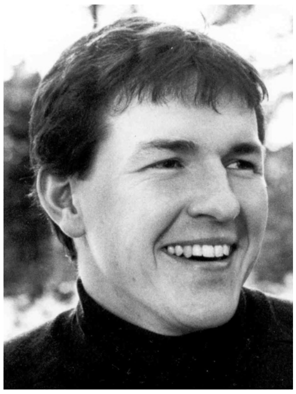

Ingela Lind was born in 1975. She received her M.Sc. in Applied Physics and Electrical Engineering in 1998 and her Lic.Eng. in 2001 both at Linköping University. Current research interest is regressor selection for onlinear black-box models.
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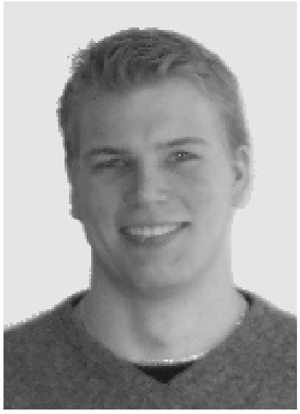

Niclas Persson was born in 1975. He received his M.Sc. in Applied Physics and Electrical Engineering in 2000 and his Lic.Eng in 2002 both at Linköping University. He is also employed by NIRA Dynamics AB from where he is partly on leave to complete his Ph.D.
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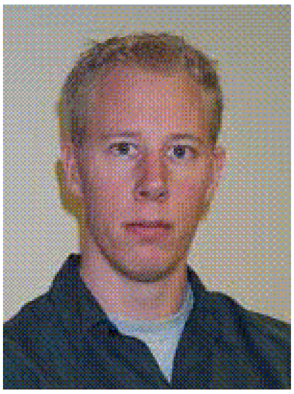

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Magnus Åkerblad was born in 1976. He received his M.Sc. in Materials Technology in 2000 from the Royal Institute of Technology, Stockholm. His research interests include optimization for MPC.
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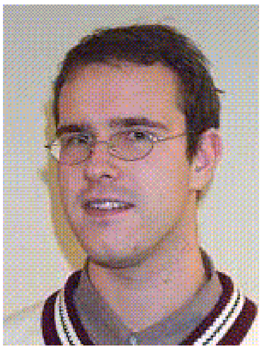

Jonas Gillberg was born in 1975. He received his M.Sc. in Applied Physics and Electrical Engineering in 2001 from Linköping University.
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Thomas Schön was born in 1977. In 2001 he received his BSc degree in Business Administration and Economics, and his MSc degree in Applied Physics and Electrical Engineering, both from Linköping University. His research interests are in signal processing and system identification.
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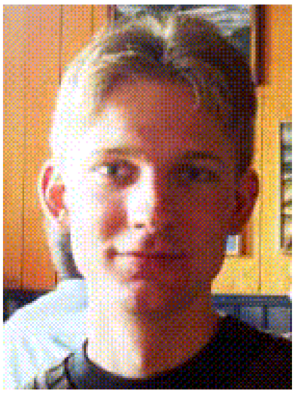

Joakim Svensèn, was born in 1977. He is employed as research engineer at the Division since December 2000, where he is responsible for the laboratory equipment.
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Sören Hansson is employed as research engineer at the Division on a part time basis, where he is responsible for the laboratory equipment.
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Per Stolpe 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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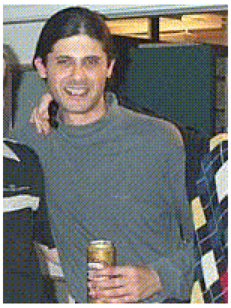
Ulla Salaneck is secretary for the control group.
`email: ulla@isy.liu.se`

Visitors

Alxander Nazin, Institute of Control Sciences, RAS, Moscow, Russia, visited the department during January and February 2002.

Sunil Kukreja, McGill University, Montreal, Canada, was a postdoctoral fellow from September 2001 to August 2002.



Joe Qin, University of Texas at Austin, visited the department during March 2002.

Paul Hriljac, Embry-Riddle Aeronautical University, Prescott AZ, visited the department from July 2002 to October 2002.

Dalius Navakauskas, Vilnius Gidiminas Technical University, Vilnius, Lithuania, visited the department from October 2002 to March 2003.

Rimantas Pupeikis, Vilnius Gidiminas Technical University, Vilnius, Lithuania, visited the department from November 2002 to June 2003.

Andrius Usinskas, Vilnius Gidiminas Technical University, Vilnius, Lithuania, visited the department during November 2002.

Simone Paoletti, University of Siena, Italy, visited the department from November 2002 to March 2003.

Liu Goncalves, University of Porto, Portugal, visited the department during October 2002.

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+TB Mechanical Engineering and Engineering Biology Programs. 180 participants. Lecturer: Anna Hagenblad.

  Y Applied Physics and Electrical Engineering. 150 participants. Lecturer: Lennart Ljung.

  D Computer Engineering Program. 90 participants. Lecturer: Anna Hagenblad.

  I Industrial Engineering and Management. 150 participants. Lecturer: Svante Gunnarsson.

- *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. 60 participants. Lecturer: Anders Hansson.

- *Control Theory I* (Reglerteori I) For the Industrial Engineering and Management and Mechanical Engineering Programs. Multivariable systems, Sampled data systems, LQG-control. 20 Participants. Lecturer: Mikael Norrlöf.

- *Automatic Control M, advanced course* (Reglerteknik, fortsättningskurs M). For the Mechanical Engineering Program. Modelling, Bond graphs, System Identification, Nonlinear systems, Signal processing. 20 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. 60 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. 65 participants. Lecturer: Torkel Glad.

- *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. 70 participants. Lecturer: Inger Klein.

- *Real Time Process Control* (Realtidsprocesser och reglering). For the Information Technology Program. Real time systems. PID control. 25 participants. Lecturer: Inger Klein.

- *Linear Feedback Systems* (Återkopplade linjära system). For the Information Technology Program. Linear systems, controllability, observability, feedback control. 25 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, 20 Participants. Lecturer: Anders Hansson.

- *Introduction to MATLAB* (Introduktionskurs i MATLAB). Available for several Engineering Programs. 1200 Participants. Lecturer: Fredrik Gustafsson.

- *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, 24 Participants. Lecturer: Svante Gunnarsson and Kent Hartman.

- *Perspectives to computer technology* (Perspektiv på datateknik). Project work with focus on computer technology, 12 Participants. Lecturer: Kent Hartman.

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

- *Automatic control, EI* (Electrical Engineering) 5 units, 35 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, 35 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, 90 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: Anna Hagenblad.

B.2 Graduate Courses

- *Adanced Issues in Non-parametric Signal Processing.* Lecturer Gustafsson. Literature: Various articles and book chapters.

- *Linear Systems.* Lecturer Torkel Glad. Literature: Wilson J. Rugh, Linear System Theory, Prentice Hall, 1996., T. Kailath: Linear Systems. Prentice Hall 1980

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

- *Convex Optimization for Control.* Lecturer Anders Hansson. Literature: S. Boyd and L. Vandenberghe: Convex Optimization, manuscript of forthcoming book, 2002.

Appendix C

Computers and Laboratory Equipment

The Automatic Control group uses an Ethernet based computer network with Sun Microsystems workstations and Postscript laser printers in their daily work. The group also has 11 Intel-based laptop computers. In the laboratory, mainly used by students in the different courses, there are a lot of different processes and 19 Intel-based computers for measurement and control. The students also got 24-hours access to 64 Sun Ultra 10 workstation in an Ethernet based computer network.

Comments and questions on the equipment can be directed to Joakim Svensén.

The computer network at the Division of Automatic Control consists of the following components.

- An Ethernet based 100baseT TCP/IP network
- 1 Sun SPARCserver 10 (2*2 hyperSPARC)
- 24 Sunblade 100
- 8 Sun Ultra 10
- 4 Sun Ultra 1
- 2 Dell OptiPlex PC:s
- 1 HP LaserJet 4 Si/MX Postscript laser printer

- 1 HP LaserJet 8100DN Postscript laser printer
- 1 HP ColorJet Postscript laser printer
- 1 HP LaserJet 5 MPPostscript laser printer
- 1 Tektronix Phaser 350 solid ink-jet color printer

The Sun workstations run Solaris 2.8 and CDE (Common Desktop Environment). The software used in this network is mainly for advanced calculations and documenting. Among the mathematical programs are Matlab, Maple, Mathematica, 20sim, MathModelica, MATRIXx, Macsyma and Axiom. The system mainly used for preparing documents is TEXand LATEX. Accompanying programs such as xdvi, dvips and ghostview are also available. Write, Draw, Paint, Equation and Table from IslandGraphics, Inc., The Publisher from ArborText, Inc. and FrameMaker from Frame Corporation are other document handling packages that the network offers. The public services available (e.g. anonymous ftp areas, mail server and WWW) are described in Section 2 of this report.

The laptop computers are:

- 7 Dell Latitude (Pentium,Pentium II and Pentium III of various speed)
- 1 Acer TravelMate 516TE

In the laboratory the following processes and computers are used:

- 16 AC and DC servo systems, Feedback MS150
- 5 hot air processes, Feedback PT326
- 9 simple tank processes
- 5 double tank processes
- 6 modular systems with simulated processes, PID-Lead/lag compensation, and time discrete controllers
- 2 inverted pendulum processes
- 1 bandmachine process

- 1 air-driven generator plant
- 1 air-driven steam generator
- 1 coupled tanks process, Tecquipment CE5
- 1 ball and beam process, Tecquipment CE6
- 1 ball and hoop process, Tecquipment CE9
- 1 coupled drives process, Tecquipment CE108
- 3 Lego processes for sequential control
- 1 helicopter-like process
- 2 wind meter processes from Chalmers Institute of Technology
- 6 Dell Workstation 400
- 8 Network Crimson single Pentium III with dSPACE signal processing cards
- 3 Dell Workstation 340
- 2 Dell Workstation 220 with Allan Bradley SLC500 PLC system
- 1 LEO 386 computers with Metrabyte Dash 16 interfaces (A/D, D/A and digital I/O).
- 1 HP LaserJet 4 MP laser printer

Appendix D

Seminars

- *Various Aspects of Monte Carlo Methods In Target Tracking.* **Yvo Boers,** THALES NEDERLAND B.V, February 14, 2002.

- *Estimation and optimization in the set membership approach.* **Antonio Vicino,** University of Siena, Italy, February 21, 2002.

- *Issues on the SIC scheme in DS/CDMA systems.* **Chiho Lee,** K-JIST, Korea, March 7, 2002.

- *Undetectable flight paths* **Jörgen Blomvall,** Department of Mathematics, Linköpings universitet, March 14, 2002.

- *Subspace Approach to Fault Identification via Reconstruction.* **Joe Qin,** University of Texas, March 19, 2002.

- *Tree-aided Classifiers Minimizing Stochastic Complexity.* **Timo Koski,** Deparment of Mathematics, Linköpings universitet, April 4, 2002.

- *Discrete Execution Monitoring of Industrial Process Controllers.* **Marcus Bjäreland,** Department of Computer and Information Science, Linköpings universitet, April 18, 2002.

- *Optimal Telecommunication Network Design.* **Kaj Holmberg,** Department of Mathematics, Linköpings universitet, April 25, 2002.

- *Tracking and Data Fusion Research at QinetiQ.* **Neil Gordon,** QinetiQ, UK, May 22, 2002.

- *Mixed time/frequency domain based robust identification.* **Pablo Parillo,** ETH, Zurich, June 3, 2002.

- *Sums of squares and convex optimization.* **Pablo Parillo,** ETH, Zurich, June 5, 2002.

- *Symmetries in Semidefinite Programming.* **Pablo Parillo,** ETH, Zurich, June 6, 2002.

- *An Introduction to Integral Quadratic Constraints.* **Ulf Jönsson,** Royal Institute of Technology, June 12, 2002.

- *Learning Curves for LMS.* **Paul Hriljac,** Embry-Riddle Aeronautical University, USA, September 12, 2002.

- *Linear Models for Nonlinear Systems.* **Pertti Mäkilä,** Tampere University of Technology, September 19, 2002.

- *Simultaneeous Routing and Resource Allocation in Wireless Data Networks.* **Mikael Johansson,** Royal Institute of Technology, Otcober 10, 2002.

- *Industriella reglerregler.* **Jonas Öhr,** Uppsala University, October 31, 2002.

- *Virtual Surgery.* **Eva Skarman,** Melerit AB, Noveber 14, 2002.

- *On dynamic systems identification using closed-loop observations.* **Rimantas Pupeikis,** Vilnius Gediminas Technical University, November 21, 2002.

- *Applications of Time-Frequency Analysis to Radar and Sonar Signal Analysis.* **Hans Strifors,** FOI, Linköping, December 12, 2002.

Appendix E

Travel and Conferences

Jonas Elbornsson participated in the International Conference on Signal and Speech Processing (ICASSP), Orlando, May, 2002 and the International Symposium on Circuits and Systems (ISCAS), Phoenix, May 2002

Martin Enqvist participated in Reglermöte 2002 in Linköping, Sweden, May 29-30, in the ERNSI Workshop on System Identification in Le Croisic, France, September 23-25, in the Fourth Conference on Computer Science and Systems Engineering in Linköping (CCSSE) in Norrköping, Sweden, October 23-24 and in the 41st IEEE Conference on Decision and Control in Las Vegas, USA, December 10-13.

Erik Geijer Lundin participated at the International Conference on Communication, New York, April 2002, RadioVetenskap och Kommunikation, Stockholm, June, 2002, 8th Annual Swedish Workshop on Wireless Systems 2002, Vadstena, December, 2002

Markus Gerdin participated in the IFAC 15th World Congress, Barcelona, July, 2002.

Joans Gillberg participated in Reglermöte2002, May 29-30, Linköping, Sweden, the 25th Triennial World Congress of the International Federation of Automatic Control, July 21-26, Barcelona, Spain and in Workshop on semidefinite programming and its applications in control theory, combinatorial and global optimization, September 27, 2002, LAAS-CNRS, Toulouse, France.

Fredrik Gunnarsson participated in the International Conference on Communications, New York, NY, USA, April, 2002, RadioVetenskaplig Konferens, Stockholm, Sweden, June, 2002, IFAC World Congress, Barcelona, Spain, July, 2002, and the Swedish Workshop on Wireless Systems, Vadstena, Sweden, December, 2002.

Frida Gunnarsson participated in RadioVetenskap och Kommunikation, Stockholm, May, 2002, the Conference on Computer science and Systems Engineering, Norrköping, October, 2002, and and the Wireless Systems Workshop, Vadstena, December, 2002.

Svante Gunnarsson participated in the 15th IFAC World Congress, Barcelona, Spain, July 2002.

Fredrik Gustafsson participated in Svenska navigationsdagarna, Stockholm, April 24, Reglermöte, Linköping, May, 30-31, Swedish Radio Science Conference (RVK'02), Stockholm, June, 10-13, International Federation of Automatic Control (IFAC) World Congress, Barcelona, July 21-26, European Signal Processing Conference (EUSIPCO'01), Toulouse, France, September 3-4, CCSSE'01 workshop, Norrköping, October 23, the French network ISIS' workshop on particle filtering, Paris, France, December 2, A national workshop on Wireless Communication Systems, Vadstena, Sweden, December 4-5.

Anna Hagenblad participated in Reglermöte, Linköping, Sweden, May, 2002, and the ISIS Workshop, Linköping, Sweden, November, 2002.

Anders Hansson participated in SIAM Conference on Optimization, Toronto, May, 2002, IFAC 15th World Congress, Barcelona, July, 2002, Workshop on Semidefinite Programming and its Applications in Control Theory, Combinatorial and Global Optimization, Toulouse, September, 2002, and the 41st IEEE Conference on Decision and Control, Las Vegas, December 2002. He also visited the Swiss Federal Institute of Technology (ETH), Zurich, June, 2002, University of California, Los Angeles, December, 2002, and Stanford University, Stanford, December, 2002.

Kent Hartman participated in TEKIT-dagen, April 18, Reglermöte 2002, May 29-30, Konferens om college- och distansutbildning, September 20, CUL-dagen November 11 and Tillgänglighet på webben, December 12, all in Linköping.

Ola Härkegård participated in Reglermöte, Linköping, May, 2002, the AIAA Guidance, Navigation, and Control Conference and Exhibit, Monterey, August, 2002, the fourth Conference on Computer Science and Systems Engineering in Linköping (CCSSE'02), Norrköping, October, 2002, and the 41st IEEE Conference on Decision and Control (CDC'02), Las Vegas, December, 2002.

Inger Klein participated in the Thirteenth International Workshop on Principles of Diagnosis (DX-02), Semmering, Austria, May, 2002.

Ingela Lind participated in the 15th IFAC World Congress in Barcelona, July, 2002.

David Lindgren participated in Reglermöte 2002 in Linköping, Sweden, May 29-30, and in the International Conference on Trends in Monitoring and Control of Life Science Applications in Lyngby, Denmark, October 7-8, and in the 41st IEEE Conference on Decision and Control in Las Vegas, Nevada, December 10-13.

Lennart Ljung visited INRIA January 14 -16 as a member of an evaluation team. April 29 to May 3 he was at MIT, Cambridge and University of Maryland, for the advisory committe meeting of the Institute for Systems Research. He participated in REGLERMÖTE 2002 in Linköping, May 28 - May 30, and in the International Symposium on Advanced Control of Industrial Processes (ADCONIP) in Kumamoto, Japan, June 14 -17. He took part in the Irish signals and Systems Conference (ISSC) 2002, on 25th-26th June in Cork, Ireland, and the 15th IFAC World Congress, Barcelona, July 21 to 26. September 22 to 25 he participated in the ERNSI meeting in Le Croisic, France, and November 15 - 16 he was at the Conference in honor of Anders Lindquist's 60th birthday in Stockholm. He took part in the Conference on Decision and Control, CDC, in Las Vegas, Nevada, December 9 - 13.

Mikael Norrlöf participated in Reglermöte 2002, Linköping, Sweden, May, 2002, the 15th IFAC World Congress, Barcelona, July, 2002, and the 4th Asian Control Conference (ASCC 2002), Singapore, September, 2002.

Niclas Persson participated in the Society of Automotive Engineers World Congress, Detroit, March, 2002, the CCSSE, Norrköping, 2002.

Jacob Roll visited Università degli Studi di Siena, Italy, in April-May, 2002, and participated in the IFAC World Congress, Barcelona, Spain, July, 2002, the ERNSI Workshop, Le Croisic, France, September, 2002, and the IEEE Conference on Decision and Control, Las Vegas, USA, December, 2002.

Ulla Salaneck participated in RadioVetenskap och Kommunikation, Stockholm, June, 2002 and in the ERNSI Workshop on System Identification in Le Croisic, France, September 23-25.

Thomas Schön participated in the IFAC World Congress on Automatic Control, Barcelona, July 2002, the ERNSI Workshop, Le Croisic, September 2002.

Fredrik Tjärnström participated in the international symposium on Advanced Control of Industrial Processes (AdCONIP), Kumamoto, Japan, June, 2002, the 15th IFAC World Congress, Barcelona, Spain, July 2002, the 11th ERNSI annual workshop, Le Croisic, France, September 2002, and the 4th Conference on Computer Science and Systems Engineering (CCSSE), Norrköping, Sweden, October, 2002.

Erik Wernholt participated in the ERNSI Workshop on System Identification in Le Croisic, France, September 23-25.

Magnus Åkerblad participated in the IFAC 2002 World Congress, Barcelona, July 2002, the Workshop on Semi-definite Programming, Toulouse, September 2002.

Måns Östring participated in Reglermöte 2002, Linköping, Sweden, May, 2002; International Symposium on Advanced Control of Industrial Processes (AdCONIP), Kumamoto, Japan, June, 2002; the 15th IFAC World Congress, Barcelona, July, 2002, and the 4th Asian Control Conference (ASCC 2002), Singapore, September, 2002.

Appendix F

Lectures by the Staff

- Jonas Elbornsson: *Blind Equalization of Distortion in A/D Converters.* Seminar at Department of Signals, Sensors and Systems, Royal Institute of Technology (KTH), Stockholm, Sweden, January 29, 2002.
- Martin Enqvist: *Estimating nonlinear systems in a neighborhood of LTI-approximants*, 41st IEEE Conference on Decision and Control, Las Vegas, USA, December 10, 2002.
- Frida Gunnarsson: *Communication and Control* Lecture in CUGS Communication Course, Norrköping, September, 2002
- Frida Gunnarsson: *Issues on Performance Measurements of TCP* CCSSE'02, Norrköping, October, 2002.
- Ola Härkegård: *Dynamic control allocation for overactuated aircraft.* Reglermöte, Linköping, Sweden, May 30, 2002.
- Ola Härkegård: *Dynamic control allocation using constrained quadratic programming.* AIAA Guidance, Navigation, and Control Conference and Exhibit, Monterey, California, August 6, 2002.
- Ola Härkegård: *Resolving actuator redundancy – Control allocation vs linear quadratic regulation.* CCSSE'02, Norrköping, Sweden, October 23, 2002.
- Ola Härkegård: *Efficient active set algorithms for solving constrained least squares problems in aircraft control allocation.* 41st IEEE Con-

ference on Decision and Control, Las Vegas, Nevada, December 11, 2002.

- Ola Härkegård: *Backstepping control of a rigid body*. 41st IEEE Conference on Decision and Control, Las Vegas, Nevada, December 13, 2002.

- Fredrik Gunnarsson: *Uplink admission control in WCDMA based on relative load estimates*. International Conference on Communications, New York, NY, USA, April 29, 2002.

- Fredrik Gunnarsson: *Power Control in Wireless Communications Networks - from a Control Theory Perspective*. IFAC World Congress, Barcelona, Spain, July 24, 2002.

- Svante Gunnarsson: *A simulation and animation tool for studying multivariable control*. 15th IFAC World Congress, Barcelona, Spain, July 2002.

- Fredrik Gustafsson: *Particle filter framework for navigation*. Svenska navigationsdagarna, Stockholm, Sweden, April 24, 2002.

- Fredrik Gustafsson: *Stochastic fault diagnosability in parity spaces*. IFAC'02, Barcelona, Spain, July 23, 2002.

- Fredrik Gustafsson: *Particle filter framework for target tracking*. Workshop on tracking and target classification in networks, FOI, Linköping, Sweden, August 27, 2002.

- Fredrik Gustafsson: *Particle filtering framework for positioning in wireless networks*. EUSIPCO'01, Toulouse, France, September 4, 2002.

- Fredrik Gustafsson: *Particle filter for positioning in wireless networks*. The French network ISIS' workshop on particle filtering, Paris, France, December 2, 2002.

- Fredrik Gustafsson: *Survey on positioning in wireless networks*. Wireless Communication Systems Workshop, Vadstena, Sweden, December 5, 2002.

- Anders Hansson: *Efficient Solution of Semidefinite Programs for Analysis if Gain Scheduled Controllers.* SIAM Conference on Optimization, Toronto, Canada, May 20, 2002.

- Anders Hansson: *Efficient Solution of Second Order Cone Program for Model Predictive Control.* Seminar at Automatic Control Laboratory, Swiss Federal Institute of Technology (ETH), Zurich, Switzerland, June 14, 2002.

- Anders Hansson: *A Primal-Dual Interior-Point Method for Robust Optimal Control of Linear Discrete-Time Systems.* Seminar at Division of Optimization, Linköpings universitet, Linköping, Sweden, September 25, 2002.

- Anders Hansson: *Modellprediktiv reglering.* Seminar at Swedish Research Council, Stockholm, Sweden, November 20, 2002.

- Kent Hartman *Utökad kontakt med regionens gymnasieskolor.* Linköpings universityet, May 15, 2002.

- Kent Hartman *Bygga broar till ungdomsskolan. Anpassning till nya och förändrade förkunskape.* NORDTEK, nätverk för rektorerna vid de 18 tekniska högskolorna i Norden. Umeå 17/6 2002.

- David Lindgren: *Clustered Regression Analysis*, 41st IEEE Conference on Decision and Control, Las Vegas, USA, December 10, 2002.

- Lennart Ljung: *Integrated Systems for Industrial control and Supervision: A VINNOVA Compentence Center* Institute for Systems Research, University of Maryland, MD, May 2, 2002.

- Lennart Ljung: *System Identification and Simple Process Models*, International Symposium on Advanced Control of Industrial Processes (ADCONIP), Kumamoto, Japan, June 11, 2002

- Lennart Ljung: *From Data to Model: A status report on system identification*, The Irish Signals and Systems Conference (ISSC'02), Cork, Ireland, June 25, 2002

- Lennart Ljung; *A course on system identification*, Cork Institute of Technology, Cork, Ireland, June 24, 2002

- Lennart Ljung: *Future challenges for system identification*, the ERNSI meeting, Le Croisic, France, Sept 23, 2002
- Lennart Ljung: *Modeling and identification: Approaches and challenges*, the ERNSI meeting, Le Croisic, France, Sept 24, 2002
- Lennart Ljung: *Linear system identification as curve fitting*, The Anders Lindquist Conference, KTH, Stockholm, November 16, 2002 cdc
- Lennart Ljung: *Identification for Control: simple process models*, The 41st IEEE Conference on Decision and Control, Las Vegas, NV, December 13, 2002
- Mikael Norrlöf: *A General Framework for Iterative Learning Control*. 15th IFAC World Congress, Barcelona, July 24, 2002.
- Mikael Norrlöf: *Disturbance aspects of high order Iterative Learning Control*. 15th IFAC World Congress, Barcelona, July 25, 2002.
- Mikael Norrlöf: *Ongoing activities in the ROBOTICS group at Linköpings universitet*. Seminar at the Department of Electrical and Computer Engineering, National University of Singapore, Singapore, September 23, 2002.
- Mikael Norrlöf: *Iterative Learning Control – in theory and practice*. Seminar at the School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore, September 24, 2002.
- Mikael Norrlöf: *Iteration varying filters in Iterative Learning Control*. 4th Asian Control Conference, Singapore, September 27, 2002.
- Mikael Norrlöf: *Some new results on Current Iteration Tracking Error ILC*. 4th Asian Control Conference, Singapore, September 27, 2002.
- Jacob Roll: *A Direct Weight Optimization Approach to Local Modelling*. ERNSI Workshop, Le Croisic, France, September 23, 2002.
- Jacob Roll: *A Non-Asymptotic Approach to Local Modelling*. CCSSE'02, Norrköping, Sweden, October 23, 2002.
- Jacob Roll: *A Non-Asymptotic Approach to Local Modelling*. CDC'02, Las Vegas, USA, December 11, 2002.

- Fredrik Tjärnström: *Variance properties of model reduction.* Seminar at Department of Signals, Sensors and Systems, Royal Institute of Technology (KTH), Stockholm, Sweden, May 23, 2002.
- Fredrik Tjärnström: *Modeling of industrial robot for identification, monitoring, and control.* AdCONIP'02, Kumamoto, Japan, June 9, 2002.
- Fredrik Tjärnström: *Variance aspects of L_2 model reduction when undermodeling – the output error case.* IFAC'02, Barcelona, Spain, July 26, 2002.
- Fredrik Tjärnström: *Model reduction and system identification.* ERNSI Workshop 2002, Le Croisic, France, September 24, 2002.
- Magnus Åkerblad: *Efficient solution of second order cone program for model predictive control.*
- Måns Östring: *Modeling and identification of a mechanical industrial manipulator.* 15th IFAC World Congress, Barcelona, July 25, 2002.
- Måns Östring: *Recursive identification of physical parameters in a flexible robot arm.* 4th Asian Control Conference, Singapore, September 27, 2002.

Appendix G

Publications

PhD Theses

[1] Fredrik Tjärnström. *Variance Expressions and Model Reduction in System Identification*. PhD thesis, Feb 2002.

Licentiate Theses

[2] Rickard Karlsson. Simulation based methods for target tracking. Technical Report Licentiate Thesis no. 930, Department of Electrical Engineering, Linköping University, SE-581 83 Linköping, Sweden, Feb 2002.

[3] Per-Johan Nordlund. Sequential monte carlo filters and integrated navigation. Technical Report Licentiate Thesis no. 945, Department of Electrical Engineering, Linköping University, SE-581 83 Linköping, Sweden, May 2002.

[4] Måns Östring. Identification, diagnosis, and control of a flexible robot arm. Technical Report Licentiate Thesis no. 948, Department of Electrical Engineering, Linköping University, SE-581 83 Linköping, Sweden, Jun 2002.

[5] Claes Olsson. Active engine vibration isolation using feedback control. Technical Report Licentiate Thesis no. 968, Department of Electrical Engineering, Linköping University, SE-581 83 Linköping, Sweden, Aug 2002.

[6] Niclas Persson. Event based sampling with application to spectral estimation. Technical Report Licentiate Thesis no. 981, Department of Electrical Engineering, Linköping University, SE-581 83 Linköping, Sweden, Dec 2002.

[7] David Lindgren. Subspace selection techniques for classification problems. Technical Report Licentiate Thesis no. 995, Department of Electrical Engineering, Linköping University, SE-581 83 Linköping, Sweden, Dec 2002.

Journal Papers and Book Chapters

[8] Dietmar Bauer and Lennart Ljung. Some facts about the choice of the weighting matrices in Larimore type of subspace algoithms. *Automatica*, 38(5):763–774, May 2002.

[9] Krister Edström and Torkel Glad. Algorithmic, physically based mode initialization when simulating hybrid systems. *Journal of Systems and Control Engineering*, 216:65–72, Feb 2002.

[10] Wolfgang Reinelt, A. Garulli, and Lennart Ljung. Comparing different approaches to model error modeling in robust identification. *Automatica*, 38(5):787–803, May 2002.

[11] Fredrik Tjärnström and Lennart Ljung. Estimating the variance in case of undermodeling using bootstrap. *IEEE Trans. Automatic Control*, AC-47(2):395–398, Feb 2002.

[12] Lennart Ljung. Prediction error methods. *Circuits, Systems and Signal Processing*, 21(1):11–21, Jan 2002.

[13] Lennart Ljung. Recursive identification algorithms. *Circuits, Systems and Signal Processing*, 21(1):57–68, Jan 2002.

[14] A.V. Nazin and Lennart Ljung. Asymptotically optimal smoothing of averaged lms estimates for regression parameter tracking. *Automatica*, 38(9):1287–1293, Aug 2002.

[15] V. Verdult, Lennart Ljung, and M. Verhaegen. Identification of composite local linear state space models using a projected gradient search. *Int. Journal Control*, 75(16/17):1385–1398, 2002.

[16] Mikael Norrlöf. An adaptive iterative learning control algorithm with experiments on an industrial robot. *IEEE Transactions on Robotics and Automation*, 18(2):245–251, Apr 2002.

[17] Mikael Norrlöf and Svante Gunnarsson. Experimental comparison of some classical iterative learning control algorithms. *IEEE Transactions on Robotics and Automation*, 18(4):636–641, Aug 2002.

[18] Fredrik Tjärnström and Lennart Ljung. L-2 model reduction and variance reduction. *Automatica*, 38(9):1517–1530, Sep 2002.

[19] Mikael Norrlöf and Svante Gunnarsson. Time and frequency domain convergence properties in iterative learning control. *International Journal of Control*, 75(14):1114–1126, 2002.

[20] Fredrik Gustafsson, Fredrik Gunnarsson, Niclas Bergman, Urban Forssell, Jonas Jansson, Rickard Karlsson, and Per-Johan Nordlund. Particle filters for positioning, navigation and tracking. *IEEE Transactions on Signal Processing*, 50(2), Feb 2002.

Conference Papers

[21] Mikael Norrlöf and Svante Gunnarsson. Disturbance aspects of high order iterative learning control. In *Proceedings of the 15th IFAC World Congress*, Barcelona, Spain, Jul 2002.

[22] David Lindgren and Lennart Ljung. Clustered regression analysis. In *Proc. of the 41st IEEE Conference on Decision and Control*, pages 1838–1844, Las Vegas, NV, Dec 2002.

[23] Mikael Norrlöf. Iteration varying filters in iterative learning control. In *Proceedings of the 4th Asian Control Conference (ASCC 2002)*, Singapore, Singapore., Sep 2002.

[24] A.V. Nazin and Lennart Ljung. Asymptotically optimal smoothing of averaged lms for regression parameter tracking. In *Proc. of the 15th IFAC Congress*, Barcelona, Spain, July 2002.

[25] Fredrik Gunnarsson and Fredrik Gustafsson. Power control in wireless communications networks - from a control theory perspective. In *Proc. IFAC World Congress*, Barcelona, Spain, Jul 2002.

[26] Fredrik Gunnarsson, Erik Geijer Lundin, G. Bark, and N. Wiberg. Uplink admission control in wcdma based on relative load estimates. In *Proc. International Conference on Communications*, New York, NY, USA, Apr 2002.

[27] Per-Johan Nordlund, Fredrik Gunnarsson, and Fredrik Gustafsson. Particle filters for positioning in wireless networks. In *Proc. of EU-SIPCO*, Toulouse, France, Sep 2002.

[28] Magnus Åkerblad and Anders Hansson. Efficient solution of second order cone program for model predictive control. In *IFAC 2002*, July 2002.

[29] Anders Hansson and Ragnar Wallin. Efficient solution of semidefinite programs for analysis of gain scheduled controllers. In *SIAM Conference on Optimization*, Toronto, Canada, May 2002. SIAM.

[30] Fredrik Gustafsson. Stochastic observability and fault diagnosis of additive changes in state space models. In *Proceedings of IEEE International Conference on Signal and Speech Processing*, Apr 2002.

[31] L. L Xie and Lennart Ljung. Estimate physical parameters by black-box modeling. In *Proc. of the 21st Chinese Control Conference*, pages 673 – 677, Aug 2002.

[32] M. Andersson, Svante Gunnarsson, Torkel Glad, and Mikael Norrlöf. A simulation and animation tool for studying multivariable control. In *Proceedings of the 15th IFAC Congress*, Barcelona, Spain, July 2002.

[33] D. Nesic, I.M.Y. Mareels, Torkel Glad, and Mats Jirstrand. The grobner basis method in contorl theory: An overview. In *Proceedings of the 15th IFAC Congress*, Barcelona, Spain, July 2002.

[34] Lennart Ljung. System identification and simple process models. In Z. Iwai, editor, *Proc. AdCONIP 02, Int. Symposium on Advanced Control of Industrial Processes*, pages 13 – 24, Kumamoto, Japan, Jun 2002.

[35] Måns Östring and Svante Gunnarsson. Recursive identification of physical parameters in a flexible robot arm. In *4th Asian Control Conference*, Jun 2002.

[36] Mikael Norrlöf and Svante Gunnarsson. Some new results on current iteration tracking error ilc. In *Proceedings of the 4th Asian Control Conference (ASCC 2002)*, Jun 2002.

[37] Mikael Norrlöf, Fredrik Tjärnström, and Måns Östring. Modeling and identification of a mechanical industrial manipulator. In *Proceedings of the 15th IFAC World Congress*, Barcelona, Spain, Jul 2002.

[38] O. Markusson, H. Hjalmarsson, and Mikael Norrlöf. A general framework for iterative learning control. In *Proceedings of the 15th IFAC World Congress*, Barcelona, Spain, Jun 2002.

[39] Måns Östring, Fredrik Tjärnström, and Mikael Norrlöf. Modeling of industrial robot for identification, monitoring, and control. In *Proceedings of International Symposium on Advanced Control of Industrial Processes, AdCONIP*, pages 85–90, Jun 2002.

[40] Erik Geijer Lundin, Fredrik Gunnarsson, and Fredrik Gustafsson. Uplink load estimation in wcdma. In *RVK02*, Stockholm, Sweden, mar 2002.

[41] Martin Enqvist and Lennart Ljung. Approximation of nonlinear systems in a neighborhood of lti systems. In *Reglermöte 2002*, pages 289–291, May 2002.

[42] D. Lawesson, U. Nilsson, and Inger Klein. Fault isolation using process algebra models. In *13th International Workshop on Principles of Diagnosis (DX-02)*, pages 172–178, Semmering, Austria, May 2002.

[43] Rickard Karlsson. Various topics on angle-only tracking using particle filters. In *Reglermöte 2002 – Preprints*, pages 220–225, May 2002.

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[47] Ingela Lind. Regressor selection with the analysis of variance method. In *15th IFAC World Congress, Barcelona, Spain, 21-26 July,2002*, pages T–Th–E 01 2, Jul 2002.

[48] S. J. Qin, Lennart Ljung, and J. Wang. Subspace identification methods using parsimonious model formulation. In *Proc AIChE Annual Meeting 2002*, number Paper 255c, Indianapolis, IN, USA, Nov 2002.

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[54] Ola Härkegård. Resolving actuator redundancy - control allocation vs linear quadratic regulation. In *Proc. of the Fourth Conference on Computer Science and Systems Engineering in Linköping*, pages 17–21, Oct 2002.

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[56] Ola Härkegård. Efficient active set algorithms for solving constrained least squares problems in aircraft control allocation. In *Proc. of the*

41st IEEE Conference on Decision and Control, pages 1295–1300, Dec 2002.

[57] Martin Enqvist and Lennart Ljung. Estimating nonlinear systems in a neighborhood of lti-approximants. In *Proc. of the 41st IEEE Conference on Decision and Control*, pages 1005–1010, Las Vegas, NV, Dec 2002.

[58] Martin Enqvist. Linear models of nonlinear fir systems with gaussian inputs. In *Proc. of the Fourth Conference on Computer Science and Systems Engineering in Linköping*, pages 147–151, Oct 2002.

[59] Fredrik Tjärnström. Variance aspects of l2 model reduction when undermodeling - the output error case. In *Proceedings of the 15th IFAC World Congress*, Barcelona, Spain, Jul 2002.

[60] Jacob Roll, A. Nazin, and Lennart Ljung. A non-asymptotic approach to local modelling. In *Proc. 41st IEEE Conference on Decision and Control*, Las Vegas, USA, Dec 2002.

[61] Jacob Roll, A. Nazin, and Lennart Ljung. A non-asymptotic approach to local modelling. In *Fourth Conference on Computer Science and Systems Engineering in Linköping*, pages 75–80, Norrköping, Sweden, Oct 2002.

[62] Jacob Roll. Robust verification of piecewise affine systems. In *IFAC World Congress*, Barcelona, Spain, Jul 2002.

[63] Frida Gunnarsson, Fredrik Gunnarsson, and Fredrik Gustafsson. Issues on performance measurements of tcp. In *Radiovetenskap och Kommunikation 2002*, Jun 2002.

[64] Johan Löfberg. Towards joint estimation and control in minimax mpc. In *Proceedings of the 15th IFAC World Congress, 2002*, Jul 2002.

[65] Johan Löfberg. Minimax mpc for systems with uncertain input gain. In *Proceedings of the 15th IFAC World Congress, 2002*, Jul 2002.

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[73] C. Grönwall and Fredrik Gustafsson. A cramer-rao lower bound expression for a scanning laser radar system. In *Proceedings of Reglermötet*, pages 126–129, Linköping University, Linköping, May 2002.

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[81] M.Östring and Svante Gunnarsson. Recursive identification of physical parameters in a flexible robot arm. In *Reglermöte*, May 2002.

Appendix H

Technical Reports

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Appendix I

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[140] Anders Lindh and Johan Tofte. Design and implementation of control laws for a generic aircraft model. Master's thesis, Department of Electrical Engineering, Linköping University, 2002.

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