Workshop on State Estimation

Book of Abstracts

Heidelberg, April 7 and 8, 2005

Location and Program

The “Workshop on State Estimation” starts on Thursday, April 7, at 8:55 in the morning, and finishes Friday, April 8, at 13:30 in the early afternoon. It takes place in the old town of Heidelberg in the Schmitthennerhaus located near the market square, under the following address:

Schmitthennerhaus - Gemeindehaus der Heiliggeistgemeinde
Heiliggeiststr. 17
69117 Heidelberg

For any questions regarding local arrangements you may call Moritz Diehl, 06221-548831 (office) or 0178-7237602 (mobile). During the workshop, in very urgent cases, you may also call the “Pfarramt”, 06221-21117, that is located within the Schmitthennerhaus.

Please consult the workshop webpage for details concerning location and accomodation: `http://www.mathematik.uni-regensburg.de/Mat8/Blank/Statest/`

Financial Support

The workshop is partially supported by the DFG within the project “Optimization based control of chemical processes” under grant BO864/10-1,
`http://www.iwr.uni-heidelberg.de/~agbock/NMPC_DFG`

Program, Thursday, April 7th, 2005

8:15-8:55	Registration
8:55-9:00	Welcome & Opening
9:00-10:00	*Uwe Hanebeck:* Progressive Bayes: A new state estimation framework for nonlinear systems
10:00-10:45	*Andrey Romanenko:* Unscented Kalman state estimation in process systems
10:45-11:15	Coffee Break
11:15-12:00	*Guillaume Goffaux:* Robust Kalman Filtering Techniques Applied to Train Positioning
12:00-12:30	*Discussion*
12:30-14:00	Lunch Break (at the market square are many restaurants)
14:00-14:45	*Philipp Kuegler:* Online Parameter Estimation in Infinite Dimensional Dynamical Systems
14:45-15:30	*Luise Blank:* State estimation from the view point of inverse problems
15:30-16:00	Coffee Break
16:00-17:00	*Toshiyuki Ohtsuka:* Continuation Method for Real-Time Computation of Nonlinear Moving Horizon State Estimation
17:00-17:45	*Moritz Diehl:* A Real-Time Optimization Algorithm for Moving Horizon State Estimation
17:45-18:15	*Discussion*
19:00	Workshop Dinner at the Heidelberger Kulturbrauerei, Leyergasse 6, 69117 Heidelberg (Phone: 06221/502980)

Program, Friday, April 8th, 2005

9:00-10:00	*Georg Bock:* Numerical Methods for Parameter and State Estimation
10:00-10:45	*Ekaterina Kostina:* Robust Parameter Estimation for Identification of Satellite Injection Orbits
10:45-11:15	Coffee Break
11:15-12:15	*Rolf Findeisen:* State estimation and model predictive control: existing results and challenges
12:15-13:00	*Rüdiger Franke:* Aspects of bringing optimization on-line
13:00-**13:30**	*Discussion followed by closing remarks*

Abstracts

Luise Blank (University of Regensburg, Germany): State estimation from the view point of inverse problems

Monitoring dynamical processes requires the estimation of the entire state, which is only partly accessible by measurements. Most quantities must be determined via model based state estimation. Hence, we shortly focus in the beginning on the observability of the system and introduce a -to the author's knowledge- new measure of observability. Since in general only noisy data are given, state estimation yields an ill-posed inverse problem. Therefore we give also a short introduction to ill-posed problems and its standard treatments. For state estimation regularization techniques are commonly applied in addition to the least squares ansatz. However, to avoid undesired bias we suggest to omit the regularization of the unknown initial data. To the authors knowledge this problem formulation has not been analysed analytically yet, which is one purpose of this talk. The first order necessary conditions of the resulting minimization problem are presented and the problem is reduced by several variables. In the linear case we show that this problem formulation leads to a well-posed problem with respect to L_2- and L_∞- disturbances. However, we show that the condition numbers of the evolving operators can be arbitrarily large if the spectral radius of the system matrix is large, i.e. if the measure of observability is low. In this context long time horizons seem to be undesired, since they lead to larger spectral radii. This potential ill-conditioning turns out to be also an issue for the numerical calculation of the state. SmallL_2 measurement errors may lead to large disturbances in the states. Nevertheless, for the probably in praxis more relevant L_∞-norm, perturbations yield errors in the initial data bounded independently of the system matrices. At the end we would like to discuss whether bias or possible ill-conditioning is more acceptable for state estimation, whether there is a way to avoid both and which norm is most appropriate.

Georg Bock (University of Heidelberg, Germany): Numerical Methods for Parameter and State Estimation

We review classical numerical methods for parameter and state estimation in ordinary differential (ODE) and differential algebraic equation (DAE) models. We focus on the Boundary Value Problem (BVP) approach, in particular the multiple shooting method, that treats both the simulation and the parameter estimation problem in one shot, and that has been developed to treat strongly nonlinear problems efficiently. Here, a large but structured constrained least squares problem is formulated and solved by a generalized Gauss-Newton method. We discuss important features of an efficient implementation like generation of derivatives, structure exploiting linear algebra, globalisation. We illustrate the methods at examples from engineering and biology.

Moritz Diehl (University of Heidelberg, Germany): A Real-Time Optimization Algorithm for Moving Horizon State Estimation

We present an online state and parameter estimation method for nonlinear dynamical systems, as needed for advanced feedback control and real-time optimization techniques, e.g. in process engineering. The estimation method uses a moving horizon approach based on past online measurements. The resulting state and parameter estimation problems are solved – online – by a multiple shooting approach for differential algebraic equations in conjunction with a Gauss Newton method. For problem regularization, if necessary, we propose to employ virtual measurements of initial state and parameters that are based on previous measurement data (lying before the horizon) and updated by a Kalman filter algorithm based on the current system linearization. We show how to initialize subsequent problems by a shift, and propose a fast "real-time iteration scheme" for online estimation, that updates the measurement data in each Gauss Newton iteration. The numerical performance and estimation capability of the algorithm is demonstrated at an example from process engineering. Joint work with H.G. Bock, L. Wirsching, P. Kühl, J. Busch, J. P. Schlöder.

Rolf Findeisen (University of Stuttgart, Germany): State estimation and model predictive control: existing results and challenges

In this talk we consider the output-feedback stabilization problem for nonlinear continuous time systems employing nonlinear model predictive control in combination with suitable state observers. In the first part we review results based on so called nonlinear separation principles and the certainty equivalence principle. Even so that these results are theoretically appealing certain restrictions limit their applicability. For example the application requires that the value function is continuous, which is often difficult to guarantee. In the second part we outline an approach based on the combination of a min-max nonlinear model predictive control schemes with observers that deliver set-based state information. Provided the observer estimates are consistent and the min-max NMPC controller is designed suitably, it is show that the closed-loop can be rendered stable.

Rüdiger Franke (ABB, Germany): Aspects of bringing optimization on-line

Modern control systems need to extend the reach of traditional automation systems - beyond control of the process- to achieve the productivity gains necessary to succeed in today's business markets. The Industrial IT System 800xA from ABB provides a scalable solution that spans and integrates loop, unit, area, plant, and interplant controls. The talk introduces into 800xA and the underlying Aspect Object technology. Aspect Objects relate all plant data and functions, the aspects, to specific plant assets, the objects. It is discussed, how this technology is applied to on-line optimization. This includes the relation of process signals to model variables, the estimation of the model state, the predictive optimization and the application of results. A Non-linear Model-based Predictive Controller (NMPC) for power plant start-up serves as example. The startup problem is challanging as it is highly non-linear in the covered large range of operation. Thermal stress occuring in thick walled components needs to be kept in given limits. However, the governing process of steam flowing through the thick walled components is not always observable during startup, in particular for low mass flow rates, parallel flow paths with lumped flow rate measurements and at the boundary between saturated and superheated steam. This is why the estimation of initial states and the use of an appropriate error model is crucial for bringing the optimization on-line.

Guillaume Goffaux (Faculté Polytechnique de Mons, Belgium): Robust Kalman Filtering Techniques Applied to Train Positioning

Position and speed are two essential variables in a vehicle application. Various levels of precision and integrity are required, depending on the objectives. For instance, from a security point of view, i.e., to avoid collisions, providing a confidence interval prevails upon precision.

State estimation techniques are a natural way to estimate these variables by blending measurements and process modelling. One can quote Kalman filtering based on GPS (Global Positioning System) and INS (Inertial Navigation System) [5], particle filtering for positioning, navigation and tracking applications [1], [2] or nonlinear filtering in maritime applications [3], [4]. However, all these techniques require an accurate model. To handle model uncertainties, robust filters have been proposed [6], which bound the l2 norm of the operator from the input disturbances and initial estimation errors to the estimation errors, provided the model uncertainties have a bounded H1 norm.

In this study, a classical Kalman filter and a robust filter are designed and compared in the context of train positioning. These filters are based on a one-dimensional kinematic model, and several sensors providing position, velocity and/or acceleration measurements at asynchronous discrete times. These sensors include odometers, radars and accelerometers. Measurements have been recorded in reallife experiments and put together in a database.

Accelerometers require a special attention as their measurements are influenced by the track gradient. The steeper the slope, the more the accelerometer output is biased by the gravity acceleration. In a real configuration, only one accelerometer is available. In order to handle the erroneous sensor output, a slightly modified version of the robust filtering algorithm described by Mangoubi [6] is developed, which takes asynchronous data into account.

Joint work with A. Vande Wouwer and M. Remy.

References:

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Uwe Hanebeck (University of Karlsruhe, Germany):
Progressive Bayes: A new state estimation framework for nonlinear systems

Often, the internal state sequence of a dynamic system is not directly available and has to be reconstructed from the system input sequence and a measurement sequence supplied by sensor devices. Here, we assume discrete-time systems with continuous states, where the measurements and the inputs are nonlinearly related to the states.

The goal is to make an estimate of the state sequence available at every time step. Of course, this estimate should incorporate the information contained in all the input and measurement samples collected up to that time step. Instead of storing all data and reprocessing them at every time step, a recursive estimator is preferred, that uses some kind of sufficient statistic as an exact compressed representation of the collected data. For that purpose, the probability density functions of the state are well suited. Once they are available, almost any type of point estimate, e.g. mean, mode, or median, can be derived.

In the case of continuous states, however, the exact probability density functions characterizing the state estimate are in general either not feasible or not well suited for recursive processing. Hence, approximations of the true densities are generally inevitable. Several different choices for representing the density of the state estimate are possible. A Gaussian mixture approximation is especially convenient as its moments can be calculated analytically.

In this talk, a new estimator is introduced, which systematically minimizes a measure of deviation between the true and the approximate density by adapting both structure and parameters of the approximation density. Hence, the estimation problem is converted to an optimization problem, which consists of finding the parameters of the approximate density.

However, this is a complicated optimization problem with many local minima. For solving this minimization problem, a new type of homotopy continuation is proposed. For that purpose, a parameterized true density is introduced, which starts from a tractable density and continuously approaches the exact density to be approximated. Based on this type of progressive processing, the original optimization problem is converted into a corresponding system of ordinary differential equations. The desired optimal density parameters are then calculated by solving the differential equations over a finite ŞtimeŤ interval. Structural adaptation of the approximation density is performed during the progression in order to modify the local approximation capabilities of the mixture approximation by changing the number of components.

For different distance measures like the squared integral deviation between the true and the approximate density or the Kullback-Leibler-distance, specific expressions for the coefficients of the system of differential equations have been derived. Upon defining a specific type of approximation density, these expressions can be further simplified. A Gaussian mixture approximation is especially convenient and yields closed-form expressions for the desired coefficients.

The method has been applied to various processing steps, i.e. , transformation of random variables, prediction step (time update) for nonlinear dynamic systems, and for including information of noisy measurements on the basis of a nonlinear measurement equation. The advantage for employing the new approach to the measurement step becomes immediately clear: Instead of including the measurement information at once, it is progressively included by modifying the prior density representing the prior knowledge gathered so far.

The proposed new state estimation approach is computationally efficient and provides systematic approximations of the underlying true densities and keeps the desired measure of deviation within a pre-specified tolerance band. If the approximation densities have separable kernels and the system nonlinearities are also separable or represented by a separable conditional density, the required multidimensional integrals can be reduced to the product of one-dimensional integrals.

Applications of new approach include the following real-world problems:

- localization in cellular radio networks, e.g. WLAN, DECT,
- source localization,
- and intention recognition in human-robot-cooperation.

Ekaterina Kostina (University of Heidelberg): Robust Parameter Estimation for Identification of Satellite Injection Orbits

The observations of satellites typically consist of range, range rates, azimuth or elevation angles. The measurement times are usually clustered, not all states are measured and outliers may occur due to ambiguity problems. From such usually few measurements the orbit of a satellite has to be recovered in order to allow the prediction of the future trajectory. Due to the fact that the actual injection orbit of a satellite may significantly deviate from the planned one, e.g. if the launcher exhibits underperformance or malfunction, a fast and reliable the determination of initial orbits using the available data is particularly important. Based on practical problems provided by European Space Agency (ESA) the talk describes typical difficulties. A mathematical formulation of orbit determination problems is described. An l1 objective function is choosen in order to reduce the influence of outliers. For the numerical treatment of orbit determination problems shooting strategies for estimation problems in nonlinear differential equations are described. Emphasis is put on the efficienct treatment of the resulting large-scale nonlinear constrained weighted l1 optimization problem. The performance of the resulting codes is demonstrated using practical test cases provided by ESA. The talk is based on joint work with H. G. Bock, G. Gienger, S. Pallaschke, J. P. Schlöder and G. Ziegler.

Philipp Kügler (Johannes Kepler University of Linz, Austria): Online Parameter Estimation in Infinite Dimensional Dynamical Systems

Online (or real time) parameter estimation finds practical applications both by itself and as part of an adaptive control system. In the infinite dimensional case, the literature discusses online algorithms for parameter estimation in parabolic or hyperbolic partial differential equations which require spatially distributed data and their differentiation with respect to the space variables. In this talk, we introduce an online parameter estimation algorithm applicable to PDEs as well as ODEs that also allows for partial state observations and makes data differentiation unnecessary. Numerical examples are presented.

Toshiyuki Ohtsuka (Osaka University, Japan): Continuation Method for Real-Time Computation of Nonlinear Moving Horizon State Estimation

In this talk, real-time algorithms for nonlinear moving horizon state estimation (MHSE) are introduced. Since a dynamic optimization problem over a finite past has to be solved at each sampling time, a fast optimization algorithm is essential for implementation of nonlinear MHSE. One of key ideas for realizing real-time optimization is exploitation of the time-dependent nature of the MHSE problem. For example, the derivative of the optimal solution with respect to time can be obtained by solving a linear two-point boundary-value problem without iterative searches, which is a kind of continuation method. This idea of the continuation method can be utilized to derive, without any discretization, an explicit differential equation for the state estimate in a similar form as the Kalman filter. It is also possible to apply the continuation method for the optimization problem discretized over the horizon. In that case, the continuation method leads to a linear algebraic equation for the derivative of the unknown variables with respect to time, and the linear algebraic equation can be solved efficiently with Krylov subspace methods. Some application examples of the continuation-based algorithms are presented, including not only MHSE but also receding horizon control of a hovercraft, ship and an automobile.

Andrey Romanenko (University of Coimbra, Portugal): Unscented Kalman state estimation in process systems

Recently, the unscented Kalman filter (UKF) algorithm, which is a new generalization of the Kalman filter for nonlinear systems, was proposed in the literature. It has significant advantages over its widely used predecessor that include better accuracy and simpler implementation. A number of applications using the UKF have been reported since then, most of them in the area of aerospace navigation and tracking where one frequently encounters severe nonlinearity and fast dynamics. However, accounts of UKF applications in process systems engineering are relatively scarce. This talk aims to provide an introduction to the UKF technique and to outline its benefits and disadvantages in a state estimation framework of simulated chemical processes. A comparison of the UKF with the linearization used in the standard extended Kalman filter is provided from a practical point of view.

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