BENELUX MEETING ON SYSTEMS & CONTROL 1988

March 2-4, 1988
Heijen (Limburg, the Netherlands)

TIME SCHEDULE AND SUMMARIES OF TALKS

Conference organization by the Centre for Mathematics and Computer Science (CWI), Amsterdam

Time Schedule
Wednesday, March 2

11.30-12.30 Jasmijn	**Plenary Session**
11.30-12.30	H. Kaufman: *Direct model reference adaptive control of multivariable systems.*
11.30-12.30 Gerbera	**Session 1a: System Theory** Organized by: SMBT (T)
14.00-14.25	P. Boekhoudt, M. A. Kaspers: *The numerical solution of the H_∞ control design problem via the polynomial approach.*
14.25-14.50	H. J. Zwart: *Stabilizability for infinite dimensional systems.*
14.50-15.15	A. H. W. Geerts: *Continuity properties of the cheap control problem without stability.*
15.15-15.40	R. Smedinga: *Control of discrete events.*
15.15-15.40 Hyacinten	**Session 1b: Control of Power Systems** Organized by: SMBT (P)
14.00-14.25	H. Aling: *Closed loop system identification of a coal-fired power plant.*
14.25-14.50	J. B. van Helmont: *Observer based optimal control strategy applied to a coal fired Benson boiler.*
14.50-15.15	M. Steinbuch, O. H. Bosgra: *Robust optimal output feedback of a wind energy conversion system.*
15.15-15.40	P. M. M. Bongers, S. Dijkstra: *Application of a nonlinear filter-controller for a wind turbine.*
15.15-15.40 Iris	**Session 1c: Robot Technology** Organized by: SMBT (B)
14.00-14.25	H. Butler, G. Honderd, J. van Amerongen: *Model-reference adaptive control of a direct-drive DC motor using a time varying reference model.*
14.25-14.50	H. Roodhart, P. Löhnberg, H. Nijmeijer: *Time-optimal control for a particular two-link robot.*
14.50-15.15	L. Kruise, J. Kouwen: *Modelling and control of a flexible robot link.*
15.15-15.40	M. H. Klompstra, J. Bontsema: *SIMSAT simulation package for flexible beams.*
16.10-17.50 Gerbera	**Session 2a: The Role of Systems Theory in Hydraulic Problem Solving** Special session organized by T. Schilperoort
16.10-16.35	J. R. Moll: *Applications of systems theory in real-time river flow forecasting.*
16.35-17.00	A. W. Heemink: *Numerical aspects of tidal filtering problems.*
17.00-17.25	C. F. de Valk: *Data-assimilation in wave prediction models.*
17.25-17.50	H. F. P. van den Boogaard: *Identification of dispersive transport models.*
16.10-17.50 Hyacinten	**Session 2b: Controller design**
16.10-16.35	P. Valk, O. H. Bosgra: *Newton methods for structured parametric LQ problems.*
16.35-17.00	V. Van Breusegem, G. Bastin, G. Campion: *State feedback traffic control of the transient behaviour of underground public transportation systems.*
17.00-17.25	J. W. Polderman: *An adaptive LQ controller for a class of first order systems.*
17.25-17.50	K. G. Woodgate: *Design of an H_∞ controller for an inverted double pendulum system via a polynomial approach.*
16.10-17.50 Iris	**Session 2c: System Technology in Rehabilitation** Special session organized by A. van Lunteren
16.10-16.30	A. van Lunteren: *System technology in rehabilitation of people with a missing or paralyzed arm.*
16.30-16.50	J. C. Cool, H. Boersma, J. van Frankenhuyzen: *Design of a hydraulic force amplifier by block diagrams.*
16.50-17.10	D. H. Plettenburg: *A pneumatic control circuit for hand prostheses.*
17.10-17.30	R. B. M. Jaspers: *Modelling the treatment process of brachial plexus injuries: the plexus system.*
17.30-17.50	G. M. Pronk: *A kinematic model of the shoulder girdle.*
20.00-21.30 G, H, I	**Meetings of the research communities of the Dutch Foundation for Measurement and Control Technology (SMBT)**

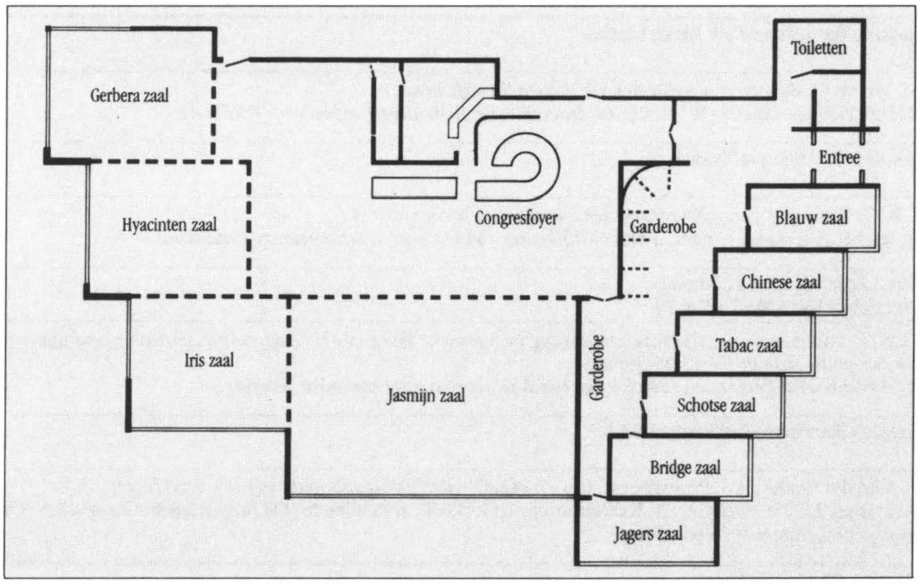
Thursday, March 3

09.00-11.00 Jasmijn	**Plenary Session**
09.00-10.00	L. Ljung: *System identification — a status report.*
10.00-11.00	Minicourse: P. C. Breedveld on the modeling of physical systems.
11.30-12.45 Gerbera	**Session 3a: Control Problems for Traffic and Transportation** Special session organized by J. H. van Schuppen
11.30-11.55	J. A. C. van Toorenburg: *Control problems motivated by motorway traffic.*
11.55-12.20	M. F. A.M. van Maarseveen: *Future scenarios for travel demand in the Netherlands.*
12.20-12.45	S. A. Smulders: *Control of freeway traffic flow.*
11.30-12.45 Hyacinten	**Session 3b: Tuning and Self-Tuning** Organized by: SMBT (B)
11.30-11.55	A. R. M. Soeterboek, H. B. Verbruggen, P. P. J. van den Bosch: *Self-tuning control of processes with signal level and rate constraints.*
11.55-12.20	H. Duetz, K. Snoek: *An adaptive autopilot for inland ships — modification of the tuning method.*
12.20-12.45	P. H. Wewerinke: *Model of the human observer and controller of a dynamic system — theory and validation.*
11.30-12.45 Iris	**Session 3c: Linear Systems I**
11.30-11.55	I. Gohberg, M. A. Kaashoek, A. C. M. Ran: *Partial pole and zero displacement by cascade connection.*
11.55-12.20	F. M. Callier, J. Winkin: *On the existence of normalized coprime fractions for multivariable distributed systems.*
12.20-12.45	H. L. Trentelman: *The regular free-endpoint LQ-problem with indefinite cost.*
11.30-12.45 Jasmijn	**Session 3d: Approximate Modelling I**
11.30-11.55	B. De Moor, J. Vandewalle, J. Staar: *The concept of oriented signal-to-signal ratio of two vector sequences and the generalized singular value decomposition.*
11.55-12.20	Y. C. Zhu: *An upper bound of the identification errors of MIMO linear processes.*
12.20-12.45	C. Heij: *A deterministic approach to approximate modelling.*
14.00-16.00 Jasmijn	**Plenary Session**
14.00-15.00	Minicourse: J. W. Nieuwenhuis on the modeling of time series.
15.00-16.00	H. Kaufman: *Application of model reference adaptive control.*
16.30-17.45 Gerbera	**Session 4a: Robotics**
16.30-16.55	B. Raucent, G. Campion, G. Bastin, J.-C. Samin: *Identification of barycentric parameters of robotic manipulators from external measurements.*
16.55-17.20	P. Maes, J. C. Samin: *Symbolic generation of dynamic and identification models for robots: linearity with respect to barycentric parameters.*
17.20-17.45	A.-M. Guillaume, G. Bastin, G. Campion: *A discrete time self tuning computed torque controller for robotic manipulators.*
16.30-17.45 Hyacinten	**Session 4b: Climate Control** Co-organized by: SMBT (P)
16.30-16.55	M. Vajta, J. E. Rijnsdorp, J. F. C. Verberne, S. F. van der Meulen: *Optimization of heat delivery to apartment buildings using an improved building model.*
16.55-17.20	P. Wouters: *The use of recursive identification techniques with regard to thermal modelling of buildings and test-cells.*
17.20-17.45	P. J. Lute, A. H. C. van Paassen: *Indoor temperature control using predictions.*
16.30-17.45 Iris	**Session 4c: Linear Systems II**
16.30-16.55	S. Q. Zhu, M. L. J. Hautus, C. Praagman: *A relation between the coprime fractions and the gap metric and its application to robust stabilization.*
16.55-17.20	M. P. M. Rocha: *A concept of state for 2-D systems.*
17.20-17.45	C. Praagman: *Input-output representations for AR-models.*
16.30-17.45 Jasmijn	**Session 4d: Identification**
16.30-16.55	B. De Moor, M. Moonen, L. Vandenberghe, J. Vandewalle: *Identification of linear state space models with singular value decomposition using canonical correlation concepts.*
16.55-17.20	W. A. Renes, R. J. P. van der Linden: *A grid search identification algorithm.*
17.20-17.45	V. Bondarev: *Some aspects of system identification using pulse frequency modulated signals.*
20.00-21.30 Jasmijn	**Annual meeting of the Dutch Foundation for Measurement and Control Technology (SMBT)**

Friday, March 4

09.00-10.00 Jasmijn	**Plenary Session**
09.00-10.00	Minicourse: G. J. Olsder on the modeling of discrete event systems.
10.00-10.50 Gerbera	**Session 5a: Software for Identification**
10.00-10.25	M. Haest, G. Bastin: *A workstation for system identification.*
10.25-10.50	R. J. P. van der Linden, W. A. Renes: *Interactive system identification with PRIMAL.*
10.00-10.50 Hyacinten	**Session 5b: Discrete Events**
10.00-10.25	J. A. C. Resing: *A central limit theorem for discrete-event systems.*
10.25-10.50	A. Barbé: *A complex system: a binary difference-field with periodic boundary conditions.*
10.00-10.50 Iris	**Session 5c: Stochastic Models** Organized by: SMBT (T & P)
10.00-10.25	H. N. J. Poulisse: *Local stochastic modelling to represent fine scale heterogeneities in coarse grid numerical models for one-phase flow through porous media.*
10.25-10.50	B. Hanzon: *A differential-geometric approach to approximate nonlinear filtering.*
10.00-10.50 Jasmijn	**Session 5d: Parameter Estimation I**
10.00-10.25	E. Van der Ouderaa, J. Renneboog: *Design of optimal input signals with very low crest factor.*
10.25-10.50	A. Dahan, I. C. W. Olievier, A. Berkenbosch, J. G. Bovill, J. de Goede: *On the parameter estimation of the respiratory control system of human beings.*
11.20-12.10 Gerbera	**Session 6a: Decoupling**
11.20-11.45	A. J. van der Schaft: *Almost decoupling and high-gain feedback in linear and nonlinear systems.*
11.45-12.10	H. J. C. Huijberts: *Input-output decoupling with stability for Hamiltonian systems.*
11.20-12.10 Hyacinten	**Session 6b: Control of Networks**
11.20-11.45	R. K. Boel, J. H. van Schuppen: *Control for load balancing given limited state information.*
11.45-12.10	P. R. de Waal: *Optimal control of a processor sharing queueing system.*
11.20-12.10 Iris	**Session 6c: Approximate Modelling II**
11.20-11.45	P. M. J. Van den Hof: *Criterion based model equivalence in multivariable system identification.*
11.45-12.10	E. M. van Beuningen: *On the estimation of an upper bound for the identification errors.*
13.30-14.45 Gerbera	**Session 7a: Nonlinear Systems**
13.30-13.55	R. Hut: *An application of suboptimal minimum variance control and filtering.*
13.55-14.20	Ch. Delépaut, G. Bastin: *A simple adaptive control scheme for a class of systems linearizable by state feedback.*
14.20-14.45	L. L. M. van der Wegen: *Some remarks on disturbance decoupling with stability for nonlinear systems.*
13.30-14.45 Hyacinten	**Session 7b: Process Control**
13.30-13.55	A. R. van Heusden, G. H. Heusinkveld: *Flexible controller structures for optimal control.*
13.55-14.20	R. Castelein, A. Lommers: *Diagnostic tests for improved process control.*
14.20-14.45	G. Dean: *Unit Operations — a batch process control system.*
13.30-14.45 Iris	**Session 7c: Discrete-Time Systems**
13.30-13.55	P. H. M. Janssen: *General results on the McMillan degree and the Kronecker indices of ARMA and MFD models.*
13.55-14.20	P. S. C. Heuberger: *Orthonormal polynomials with shift structure: extensions and transformations.*
14.20-14.45	J. C. Engwerda: *Stabilizability and detectability of time-varying discrete-time linear systems.*
13.30-14.45 Jasmijn	**Session 7d: Parameter Estimation II**
13.30-13.55	J. Chen, J. Vandewalle: *AR - ARMA parameter estimation by adaptive FIR - IIR filter.*
13.55-14.20	J. M. ten Vregelaar: *A least squares parameter estimation method for some uncommon models.*
14.20-14.45	G. van Straten, K. Keesman: *Parameter estimation in uncertain dynamic systems from signals with bounded noise.*
14.45-15.45 Jasmijn	**Plenary Session**
14.45-15.45	L. Ljung: *Adaptation and tracking in dynamical systems.*

Location of the conference rooms



CLOSED LOOP SYSTEM IDENTIFICATION OF A COAL-FIRED POWER PLANT. *)

H. Aling

In order to meet higher standards for control of coal-fired power plants, theoretical models based on physical equations are required for the purposes of dimensioning certain hardware components and of control system design. The quality of such a model, designed by Stork Boilers B.V., is judged by comparison with an experimental model of a 600 MW power plant, obtained by system identification methods.

Experiments have been performed under ordinary operating conditions, during which PRBS set point disturbances have been injected on pressure, steam flow, steam outlet temperature, temperature difference of the last spray cooler, and the reheating gas flow. By these experiments 30 data sets have been obtained, out of which 9 seemed to be useful for identification purposes. During every experiment, about 100 signals have been sampled, usually over 4 hours at a rate of 2 Hz, prefiltered by analog filters. Security precautions imposed severe limitations on the allowable set point disturbance amplitudes.

After scaling, selection and combination of signals in parallel components, trend- and postfiltering, a data set has been assembled with 7000 samples of 29 signals and a time step of 20 seconds, out of which 5000 were used for identification and 1000 for validation purposes.

Before applying parametric identification methods, signal analysis has been applied on each experimental data set separately. Nonparametric estimates have been made for combinations of scalar input/output signals by division of cross spectral densities of these signals with the set point disturbances.

Scalar models have been estimated by RLS and IV methods. The IV estimates appeared to be extremely sensitive to the choice of the model order, when judged on the input/output behaviour of the deterministic part. As there are no practical methods to determine the right IV model order or, in the multivariable case the model structure, the IV method was rejected for further use. Instead, the RPE method [1] was applied for identification of multivariable models. However, the results indicate that also this method depends heavily on the choice of model structure or identification method (equation error, output error etc.) and that a great number of questions, especially concerning the matter of validation, remain to be solved.

[1] "Theory and Practice of Recursive Identification", L.Ljung and T.Soderstrom, MIT Press 1983.

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A COMPLEX SYSTEM : A BINARY DIFFERENCE-FIELD WITH PERIODIC BOUNDARY CONDITIONS

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The difference-sequence of a binary sequence is the binary sequence representing the difference in value on two neighbouring sites in the original sequence. The difference-field is the ordered ensemble of all difference-sequences aligned one under the other. It is equivalent to the space-time pattern of a 1-dimensional cellular automaton under a simple asymmetric rule. Periodic boundary conditions imposed at the boundaries of the propagation net of changes which is induced by a finite change of values in the initial state, give rise to periodic bands of tilings along these boundary lines. Width and period of these bands evolve in a well-defined way, hereby exhibiting period-doubling and bandwidth doubling. A special kind of self-similarity is apparent and the pattern has a fractal skeleton. Periodic boundary conditions may themselves results from global equilibrium conditions imposed on the states in the propagation net.

<u>REFERENCES</u> :

[1] S. Wolfram : Universality and Complexity in Cellular Automata. Physica 10 D, 1984, p. 1-35. North Holland, Amsterdam.

[2] B. Mandelbrot : The fractal geometry of nature. W.H. Freeman & Company, San Francisco, 1982.

ON THE ESTIMATION OF AN UPPER BOUND FOR THE IDENTIFICATION ERRORS

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Abstract

Based upon the asymptotic theory, developed by Ljung and Yuan, Zhu defined an upper bound of modelling errors of black-box transfer function estimates and proposed algorithms for the computation.
To validate this theory, several numerical tests are performed. For these tests a MIMO process is estimated by a least squares technique based on input and disturbed output data samples. First an idealized case is considered where the input signals and the added output noise are both white noises and the output noise signals are assumed to be known.
Under these conditions the upper bound of the modelling errors is calculated, for different numbers of I/O samples for model estimation, different S/N ratios and for different model orders. The behaviour of the upper bound is also tested under more realistic conditions, namely, coloured input and output noise signals, and for unknown output noise which then has to be estimated.
The estimated upper bound of the uncertainty of the transfer function model can be used for testing the robustness of a feedback controlled system and for designing robust controllers.

Ljung, L. and Z.D. Yuan (1985)
Asymptotic properties of black-box identification of transfer functions.
IEEE Trans. Autom. Control, Vol. AC-30, p. 514-530.

Yuan, Z.D. and L. Ljung (1984)
Black-box identification of multivariable transfer functions:
Asymptotic properties and optimal input design.
Int. J. Control, Vol. 40, p. 233-256.

Zhu, Y.C. (1987)
On the bounds of the modelling errors of black-box MIMO transfer function estimates.
EUT Report 87-E-183, Faculty of Electrical Engineering, Eindhoven University of Technology, The Netherlands.

The Numerical Solution of the H_∞ Control Design Problem via the Polynomial Approach

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The "standard" H_∞ optimization problem of Francis and Doyle ([1]) may be solved via the polynomial approach due to Kwakernaak ([2]). By this approach, the H_∞ optimization problem is converted, via polynomial matrix fraction conversions, to a nonlinear set of polynomial matrix equations.

It is our aim to present an algorithm to solve these polynomial equations. As these equations are of a homotopy type, we solve the equations by transformation to a nonlinear set of ordinary differential equations. The implementation of the algorithm on a digital computer can be realized by use of an algebraic formula manipulation system ([3]).

A design example illustrates the method.

References

[1] Francis, B.A. and J.C. Doyle, "Linear Control Theory with an H_∞ Optimality Criterion". *SIAM J. Contr.and Opt.*, Vol. 25, pp. 815-844, 1987.

[2] Boekhoudt, P. and H. Kwakernaak, "A Polynomial Approach to the H_∞ Control Design Method". Memorandum No. 662, University of Twente, Enschede, October 1987.

[3] Kaspers, M.A., "Het oplossen van polynoommatrix-vergelijkingen bij H_∞-optimalisatieproblemen" (in Dutch). Student project report, Dept. of Appl. Math., University of Twente, Enschede, August 1987.

Control for load balancing given limited state information

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ABSTRACT
The goal of this paper is to solve the control problem of load balancing for parallel processors given limited state information. The novelty of the problem considered below is that the control units at the parallel arrival streams of tasks have different and limited state information. This makes the problem a team problem or a distributed control problem.

The motivation for this research comes from certain types of communication switches using parallel processors. The model also describes control of a distributed processor in computer systems.

The engineering model for this problem consists of arrival streams of tasks, control units and processors. Consider n parallel streams of tasks. Each stream is connected to a control unit. Consider m parallel processors. Upon arrival of a task of one of the arrival streams, this task proceeds to the corresponding control unit. At the control unit the task is assigned to one of the parallel processors and the task proceeds to that processor. There it is either served immediately or it joins the waiting room to be served at a later time. After completion of the service the task leaves the switch. Under reasonable assumptions the mathematical model for the system described above is a continuous-time Markov process with countable state space.

The control problem is to synthesize an algorithm for the control units which assign each task to one of the parallel processors. The control units will in general have different and limited state information. For example, each control unit may have instantaneous information on the length of the waiting line of one specific processor only. The control objective is to minimize the total waiting time of the tasks. The control algorithm should be such that it is robust against deviation of the model from certain nominal assumptions. One aim of the investigation is to see how much information is necessary to achieve good performance in a robust way.

A performance analysis for the above stated approaches to the load balancing problem has been made for the case of two processors. The equilibrium distribution of the Markov chain model of the controlled switch may be computed by a variant of the matrix geometric method. Values of several performance measures have been calculated. Robustness properties of these performance measures have been investigated. The stability properties of the controlled switch are currently being studied.

A publication on the investigation reported here, is in preparation.

SYSTEM IDENTIFICATION USING PFM-SIGNALS

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Summary

Most theoretical studies of systems with pulse frequency modulated (PFM) signals are concerned with stability and optimal problems [1]. At the same time, the number of investigations devoted to digital signal processing of PFM signals are not extensive.
In this paper, some methods of digital processing of single signed PFM signals are used for identification of open loop SISO systems.
Two possibilities for application of PFM signals in system identification are considered. In accordance with these possibilities, either the system is excited by PFM signals or the system output is measured by means of a pulse-frequency modulator. For both of these cases effective computational schemes for estimation of transfer functions have been obtained with the help of correlation analysis. The very simple direct algorithm for estimating the absolute values of the transfer function is based on the following equation:

$$|H(j\omega)| = (\omega/4) \cdot \sum_{i \geq 1} \operatorname{sgn}[y(t_i)]$$

where $y(t_i)$ is the system output at pulse emission time t_i.
The utility of the suggested algorithms is illustrated by considering an estimation of the transfer function of a second order low pass filter.

[1] S.G. Tzafestas
"Pulse width and pulse frequency modulated control systems", Simulation of Control Systems, Vienna, Austria, 24-29 Sept., 1978 (Amsterdam North-Holland) p. 41-8.

APPLICATION OF A NON LINEAR FILTER–CONTROLLER FOR A WIND TURBINE

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The main purpose of a wind turbine is to convert wind energy into electric energy even under severe conditions. Under increasing wind condition the wind turbine passes through a range of operating points. This cause changes in the dynamic behaviour of the wind turbine and to undergo higher static loads. The frequently changing wind velocity causes fatigue loads in the wind turbine. For this reason a control system has to be developed minimizing the fatigue loads but optimizing at the same time the delivered electric energy.

In order to maximize the delivered energy the wind velocity, acting upon the wind turbine, has to be known accurately. The wind velocity can't be measured directly for control purposes. A solution is to calculate the wind velocity by a non linear filter. A steady–state gain is calculated using the optimal filter theory. The designed Kalman gain is acting upon a non linear model of the wind turbine and wind velocity. It is shown that integral action has to added to the model of the wind velocity in order to estimate the incoming wind velocity without a bias.

Using the estimated wind velocity the desired rotor speed is easily calculated for the maintenance of the optimal control purpose. In this study a non linear controller is used which, based upon the desired rotor speed and the non linear model of the wind turbine, calculates the control signals of the wind turbine.

It is shown that this non linear filter–controller configuration is robust against certain unmodelled disturbances and parameter variations.

IDENTIFICATION OF DISPERSIVE TRANSPORT MODELS

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At Delft Hydraulics a mathematical model system for the Rhine-Meuse estuary is developed for the Ministry of Transport and Public Works. The aim of this development is to obtain a tool to study problems in the field of tidal salt/ fresh flows, morphology, and water quality.

In these mathematical models coefficients are present whose apriori form cannot well be formulated on the basis of physical knowledge of the system. As an example we can mention friction and dispersion coefficients. In practice these coefficients are adjusted in such a way that the mathematical model shows the best agreement with reality.

This calibration procedure leads to parameter identification in a distributed parameter system. Estuarine models are rather extensive, in general nonlinear, and can only numerically be evaluated. Dependent on the physical dimension of the model (1D, 2D or 3D) such numerical evaluation can require substantial computational effort. All this pleads for an efficient parameter identification technique. Moreover, for reasons of flexibility, a technique is preferred that (conceptually) as much as possible is independent of the particular form of the distributed system, the parametrization and the dimension of the system. It appears that a method developed by Chavent [1] greatly satisfies these demands (see also [2-4]). In this off-line method gradients of a criterion are calculated on the basis of optimal control and the adjoint state system. To improve the efficiency further, quasi Newton methods are used in the iterative identification process.

At the moment the method has been implemented for an advection-dispersion model that describes estuarine salt transport. The identifiability of the parameters and the stability of the estimations have been investigated by computer simulations.

Although the method performs well there is a point of discussion. It appears that the method has a deterministic basis: it does not explicitly account for any stochastic features in model and observations (although simulations show an acceptable robustness of estimations for observation noise). The possibility of extension to a stochastic environment (system and/or observation noise) that preserves the method's effectiveness forms an interesting problem for further investigation.

[1] G. Chavent, Identification of distributed parameter systems: about the output least square method, its implementation, and identifiability. Proc. 5th IFAC symposium on identification and system parameter estimation, Vol. 1, R. Isermann, ed., Pergamon Press, New York, 1980, pp. 85-97

[2] J.P. Humeau and M. Grolleau, Coefficient control for a distributed parabolic system, Mathematics and computers in simulation , Vol 27, 1985, pp. 1-17

[3] C. Kravaris and J.H. Seinfeld, Identification of parameters in distributed parameter systems by regularization, SIAM J. Control and Optimization, Vol 23, no. 2, 1985, pp. 217-241

[4] C. Merckx, Identification of a spatially varying parameter in a time periodic parabolic system, Rapport 85/13, Department of mathematics, University of Namur

MODEL REFERENCE ADAPTIVE CONTROL OF A DIRECT-DRIVE DC MOTOR USING A TIME VARYING REFERENCE MODEL

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J. van Amerongen
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Recently, DC motors which deliver a high torque on the motor axis have become available, due to the development of new magnetic materials. The high acceleration torque of these motors enables a direct coupling of the load to the motor axis, avoiding the necessity of using a transmission. The disadvantages of such a gear train (backlash, friction) can thus be avoided using a direct-drive motor. Furthermore, the use of permanent magnets instead of conventional field windings makes this type of motor attractive for robot applications.

However, the direct coupling of the load to the motor axis involves a large sensitivity of the motor behaviour to the load inertia and the magnitude of the step input. This means that a PID controller with a fixed parameter setting cannot provide an acceptable response if the load inertia is varying.

In this lecture, a control strategy is presented which is based on the adjustment of the velocity feedback factor in a PID controller, using Model Reference Adaptive Control (MRAC) techniques. The aim of the controller is to impose a time optimal response on the motor for step input changes. To achieve this, the reference model in the MRAC controller must represent a time optimal response, which is dependent on the actual motor capacity and thus varies with the load inertia. Therefore, a least squares identification of the load inertia is used to adjust the reference model, which now depends on the actual motor capacity. The reference model, in turn, plays a key role in the motor controller.

The designed controller has been tested on a real direct-drive motor and a comparison to a fixed PID controller showed a large insensitivity to variations in the load inertia.

ON THE EXISTENCE OF NORMALIZED COPRIME FRACTIONS FOR MULTIVARIABLE DISTRIBUTED SYSTEMS

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Keywords : multivariable linear time-invariant distributed systems, normalized coprime fractions, spectral factorization, equally spaced delays.

ABSTRACT. A multivariable extension of the main results in [3] is presented. First the following spectral factorization problem is addressed : given a nonpositive real σ_0 and a parahermitian nonnegative matrix $\hat{F}(s) = \hat{F}_{\star}(s)$ with causal part $\hat{F}^{+}$ having all entries in the algebra $\hat{A}_{-}(\sigma_0)$, [1]-[2], find a necessary and sufficient condition for $\hat{F}$ to have a σ_0-invertible spectral factor $\hat{R}$. Such a condition is established for the (generic) particular case where F^{+} has equally spaced delays, [5]. As a byproduct, we can prove the existence of normalized coprime fractions, [4]-[3], for any possibly unstable system described by a transfer function matrix having all entries in $\hat{\mathbf{B}}(\sigma_0)$, [1]-[2], with equally spaced delays. This leads in turn to the extension of the graph metric, [4]-[3], to such transfer functions : this metric is equivalent to the metric introduced in [6], when our metric is applied to transfer functions in $\hat{\mathbf{B}}(0)$ having equally spaced delays and no poles on the imaginary axis.

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Subject : 7th Benelux meeting on Systems and Control

Title : Diagnostic tests for improved process control

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Abstract: The process automation group of Akzo Engineering has a team of specialists working on the topic of "diagnostic tests".
A diagnostic test is an industrial project concerning the installation, programming and operation of a process computer, connected for test purposes to the instrumentation of an operating plant during several months.
The aim is the introduction and testing of new control strategies often as part of a feasibility study for the eventual revamp of a plant.
The hardware consists of an industrial process computer and process interface operated by means of a graphics console.
The software development involves, besides the use of standard programs for human interface plus a control package, application programming using a mix of real-time calculated variables and process measurements.
Sometimes special filtering techniques are deployed to obtain better process information.

AR – ARMA Parameter Estimation by Adaptive FIR – IIR Filter

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A time series y_n can be modeled as an auto-regressive (AR) process as follows,

$$y_n = -\sum_{k=1}^{p} a_k y_{n-k}$$

More generally, the time series can be modeled as the output of a p pole and q zero filter excited by white noise (ARMA model)

$$y_n = -\sum_{k=1}^{p} a_k y_{n-k} + \sum_{k=0}^{q} b_k n_{n-k}$$

Where n_n is white noise and $b_0 = 1$. Once the parameters of the AR or ARMA model are identified the spectral estimation can be calculated.

Many AR – ARMA parameter estimation techniques have been formulated theoretically, which usually involve many matrix computations and/or iterative optimization techniques. These approaches are normally not practical for some applications because of the complexity.

Griffths [1] proposed a simple method to estimate the AR parameters by a least mean-square (LMS) adaptive FIR filter which consists of a tapped delay line.

In this contribution we propose a similar way to estimate the parameters of ARMA model by an adaptive IIR filter which consists of the conventional tapped delay line plus a feedback from the estimating error. The corresponding LMS algorithm for adjusting the weight coefficients of the adaptive IIR filter is derived. Its performance in spectral estimation is compared with Griffths' method and conventional periodogram one.

According to the simulations both our method and Griffths' one result in higher resolution than the periodogram and can distinguish two sinusoids in white noise with the frequency of 0.1 and 0.11 hz, respectively, which are recognized as only one sinusoid by the periodogram method.

When compared our method with Griffths' one it is found that they have almost the same performance if the input has high signal-to-noise ratio (SNR) and that our method is better if the SNR is low because the proposed adaptive IIR filter models ARMA process instead of AR process.

Although we only discuss in this contribution the application of the AR/ARMA parameter estimation by the LMS adaptive FIR/IIR filter in the spectral estimation, other applications, such as in system identification , are also possible.

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DESIGN OF A HYDRAULIC FORCE AMPLIFIER BY BLOCK DIAGRAMS

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The use of artificial hands and hooks is facilitated by a low operating energy. Theoretically no energy is necessary because moving the fingers requires no force and exerting a gripping force requires no displacement of the fingers. A technical realization necessitates a two-phase operating cycle: a prehension phase and a gripping phase. An automatic switching mechanism separates the two phases.

A hydraulic two-phase system has been developed. All actions are performed by motors of the piston-cilinder type with O-ring seals. The system is described.

The operation of the system is influenced by the insufficient stiffness of the hand fingers and of the hydraulic fluid, the friction in the piston seals and the excessive stiffness of the springs used. All these influences contribute to the operating force.

A block diagram of the system has been built. In simplified form it can be used for calculation and optimization. The influence of design parameters has been studied. In the design procedure the ratio between the input displacements in the prehension phase and in the gripping phase must be chosen. This choise is complicated by the many unknown ergonomic aspects of the use of artificial hands.

With friction included the block diagram of the system is too complicated for simple calculations. The system is simulated with the help of SIMBOL. In reality the friction of O-ring seals depends on manufacturing tolerances, working pressures, materials, velocities and lubrication. In the model the friction has been simplified.

A prototype of the system has been built. The measurements on the prototype are compared with the results of the simulation.

ON THE PARAMETER ESTIMATION OF THE RESPIRATORY CONTROL SYSTEM OF HUMAN BEINGS

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A waste product of the metabolism in living organisms is carbon dioxide (CO_2). It is removed from the body through lung ventilation. To minimize disturbances in the CO_2 tension of the arterial blood the lung ventilation is regulated by central chemoreceptors located in the brainstem and peripheral chemoreceptors in the carotid bodies. The only method known to non-invasively separate central and peripheral effects of CO_2 on ventilation is the technique of end-tidal forcing (DEF). In this technique the end-tidal CO_2 tension is forced to follow a prescribed pattern in time against a constant background of end-tidal O_2 tension and the ventilatory response measured breath-by-breath [1].
The respiratory controller is modelled by two parallel first-order systems with time delays (M).
We performed repeated experiments on two awake subjects during normoxia. As input signals we used square wave CO_2 challenges. Modelling the noise in the ventilation data as measurement noise (M1), estimating the parameters by the least squares method [1], gave rise to non-white residuals. Therefore the noise was modelled by measurement and process noise (M2) and measurement and parallel first-order coloured noise (M3). The parameters in M2 and M3 were estimated by a one-step prediction error method [2]. The models M2 and M3 produced "white" noise residuals. The parameters common to the three models did not differ greatly. The variances from M1 turned out to be smaller than those from M2 and M3. Simulations suggest that the variances from M1 are underestimated. It is not clear whether M2 or M3 should be preferred physiologically. From a theoretical point of view M3 is more attractive as the noise is parametrized independently from the deterministic part of the model.
It may be concluded that the DEF technique together with a model of the respiratory controller is a promising approach to get insight into the chemical control of breathing in humans.

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"Unit Operations" a batch process control system

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Twenty years ago it was accepted that any sequence task associated with our control schemes would, be implemented in machine code, be modified by recoding off-line, have little if any operator interface facilities and represent a very small percentage of our overall control strategy.

The demand for sequence control systems started to grow as computer prices fell and thus could be justified on the large scale batch plants e.g. food and rubber. More recently we have experienced a dramatic change from our traditional markets of continuous control applied to batch production plants. This new demand has come from the manufacturers of Pharmaceuticals, Organics chemicals, Agro-chemicals and Polymers, where an abundance of high value added products have been developed requiring complex and numerous process stages performed on plant specifically designed for multi-product manufacture.

On these plants the user needs to specify his batch process in terms of a series of processing operations. Ideally this specification should be independent of the detailed mechanical features of the plant. Of course the operations requested must be technically feasible in the vessels availabel on the plant, but it should not be necessary to define individual valve driving and checking procedures at the process design level. On the other hand the major quality defining parameters should be specified, as should the types of vessels required to perform the operations requested.

Having defined a process, his next need is to have a convenient way to put it into production. In most manufacturing plants, this will be done to a schedule based on current orders and market predictions. This means that a production manager defines a production plan in terms of a number of batches of each product, sufficient to satisfy the current orders by their delivery dates and maintain the finished goods stock at the desired levels. On a given site there may well be several manufacturing areas under the control of one system and each must have its individual scheduling capability.

Once in production, the plant operator needs to monitor the batches to check their progress through the plant, to respond to prompts where manual actions are demanded, to respond to alarm situations and choose appropriate recovery action and to supervise the archiving of batch records.

The types of thing required in such records are materials used, time record of important phases of a batch, trend records of selected analogue values for the duration of the batch and any batch related textual comments. All these must be collected together to form a complete set of records for the batch and are then stored for long term reference.

The Unit Operations package satisfies these needs and the structured data-base used in the solution has some additional advantages when we consider commissioning, warm restart after system failure, dualled systems and distributed batch control.

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Vos références: Nos références: Louvain-la-Neuve,

7th Benelux Meeting on Systems and Control

"A simple adaptive control scheme for a class of systems linearizable by state feedback"

Ch. Delépaut* G. Bastin

Abstract

We present a simple adaptive control scheme for nonlinear plants which are linearizable by state feedback, based on a nonlinear canonical form (state vector T), under assumption that the output is equal to T_1 (a necessary and sufficient condition on the nonlinear plant is obtained). The main result is the ability to assign the local closed loop system dynamics for a range of steady outputs. The prior knowledge necessary to implement the control law weakly depends on the structure of the linearizable plant (including the order n of the system). The order of the closed loop system equals n + 1. The result is illustrated with a simulation of the control of a microbial growth process.

* Boursier IRSIA

Abstract for the 1988 Benelux Meeting on Systems and Control, Heijen, The Netherlands, March 1988.

THE CONCEPT OF ORIENTED SIGNAL-TO-SIGNAL RATIO OF TWO VECTOR SEQUENCES AND THE GENERALIZED SINGULAR VALUE DECOMPOSITION.

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Keywords : Factor analysis, prewhitening, subspace methods, total linear least squares.

In a wide variety of systems and signal processing applications, vector sequences are measured and/or computed. In such situations, the concepts of oriented energy and signal-to-signal ratio can be fruitfully exploited. Consider 2 sequences of m-vectors $\{a_k\}$, $\{b_k\}$ with $k=1,...,n$ and the associated mxn matrices A and B with column vectors a_k and b_k ($n >> m$). The oriented energy of the sequence $\{a_k\}$ measured in the direction q is defined as :

$$E_q[A] = q^t.A.A^t.q.$$

The signal-to-signal ratio in the direction q of the two vectorsequences $\{a_k\}$ and $\{b_k\}$ is defined as

$$R_q[A,B]=E_q[A]/E_q[B].$$

These definitions can easily be generalized to subspaces.

It will be shown how the singular value decomposition of the matrix A allows to characterize from both the conceptual as well as the algorithmic point of view, the properties of the oriented energy distribution of the vector sequence $\{a_k\}$ such as extremal oriented energies and directions. Moreover, the SVD allows to represent the vector sequence by an equivalent compact vectorsequence. The properties of the signal-to-signal ratios of two vector sequences $\{a_k\}$ and $\{b_k\}$ are characterized via the Generalized Singular Value Decomposition. It is shown how the GSVD reveals extremal energies and directions of the signal-to-signal ratio. The definition of maximal minimal signal-to-signal ratios allows to compute, via the GSVD, subspaces where the first sequence $\{a_k\}$ can optimally be separated from the second one $\{b_k\}$. The framework that is presented allows to formalize modeling and identification methods in which :

- the complexity of the model is determined by the rank of certain matrices.
- the data are modeled via the properties of associated subspaces.

The theoretical and formal results are illustrated by several clarifying examples : Filtering noise from measured data (which corresponds to the classical Mahalanobis transformation and in the case of linear equations, to Gauss-Markov estimation [5]) the total linear least squares approach with specified misfit or complexity [9] and factor-analysis-like subspace methods such as the separation of the fetal ECG from the maternal ECG [7] [8], the location of narrow band sources [6] , dynamical realization theory [1] and state space identification via canonical correlation analysis [2].

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IDENTIFICATION OF LINEAR STATE SPACE MODELS WITH SINGULAR VALUE DECOMPOSITION USING CANONICAL CORRELATION CONCEPTS

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SUMMARY

Selection and identification from input-output measurements of appropriate mathematical representations are of central importance in system analysis, design and control. A state space model is a most obvious choice for a mathematical representation because of its widespread use in system theory and control. Still, reliable general purpose state space identification schemes for multivariable linear time-invariant systems have not become standard tools so far, mostly due to the computational complexity involved.

The concept of canonical correlation however, together with the total linear least squares approach, allows us to set up a new most promising identification scheme, attractive due to its utmost simplicity. The algorithm contains two conceptual steps: First a sequence of state vectors is calculated as the intersection of the row spaces of two block Hankel matrices, constructed from input-output vectors. The system matrices are then obtained at once from the total linear least squares solution of a set of linear equations, containing this state vector sequence and the measured input-output sequences. Since singular value decomposition is the main tool throughout all calculations, both steps allow a robust numerical implementation.

The performance of the algorithm has been evaluated on both simulated and industrial data sets. These simulations demonstrate the remarkable insensitivity of the identification scheme with respect to over- and underestimation of the system order.

Current research activities focus on several alternative numerical implementations, exploiting matrix structure as much as possible, updating and downdating mechanisms (adding and deleting measurements) for adaptive versions, and finally, extensions of the algorithm towards generalized state space models (singular systems).

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AN ADAPTIVE AUTOPILOT FOR INLAND SHIPS
modification of the tuning method

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SUMMARY

At Delft University of Technology an adaptive autopilot for inland ships is currently being developed. An autopilot for inland ships controls the rate of turn, instead of the heading. At the 1987 Benelux Meeting on Systems and Control the basic ideas of the autopilot, indirect adaptation and LQG control, were presented along with the first experimental results[1,2]. In the short lecture an alternative for the LQG method will be presented and results of full-scale trials will be reported.

The parameters of inland ships vary over a wide range, but the closed-loop characteristics are desired to remain similar. This appears not to be possible with LQG control, without changing the weighing factor[3]. An alternative method to tune the controller gains can be based on the desired damping of the system and the amount of excessive rudder to speed up the response. This results in a closed-loop system which has the same damping ratio for all possible values of the ship's parameters and a natural frequency which is inversely proportional to the time constant of the ship. Full-scale trials indicate that this approach is successful.

These investigations were supported (in part) by the Netherlands Technology Foundation (STW).

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STABILIZABILITY AND DETECTABILITY OF TIME-VARYING DISCRETE-TIME LINEAR SYSTEMS

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SUMMARY

In this talk discrete-time varying systems are considered.
We show that in the study of the stabilizability subspace at a fixed point in time another subspace, called the potential stabilizability subspace, plays an important natural role.
For a broad class of systems, including the time-invariant systems, we show that these two subspaces coincide. Furthermore, we prove that for any system belonging to this set, which is moreover exponentially stabilizable and exponentially detectable, the LQ-problem has an exponentially stabilizing solution.

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Continuity properties of the cheap control problem without stability

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Summary

Consider the following linear-quadratic control problem:
Infimize

$$J(x_0, u) = \int_0^\infty \|y\|^2 dt$$

subject to

$$\dot{x} = Ax + Bu,\ x(0) = x_0 \ ,$$
$$y = Cx + Du \ .$$

If D is not left invertible, then the optimal inputs and state trajectories for such problems in general are distributions ([3]). This feature of singular control problems has led many researchers to study, instead of the original problem, the so-called perturbed problem:
Infimize for small $\varepsilon > 0$

$$J_\varepsilon(x_0, u) = \int_0^\infty \|y_\varepsilon\|^2 dt \ ,$$

subject to $\dot{x} = Ax + Bu,\ x(0) = x_0$,

$$y_\varepsilon = \begin{bmatrix} y \\ \varepsilon u \end{bmatrix} = \begin{bmatrix} C \\ 0 \end{bmatrix} x + \begin{bmatrix} D \\ \varepsilon I \end{bmatrix} u \ .$$

Since for $\varepsilon = 0$ the original problem is recovered, it then is hoped that the solution of the cheap control problem yields insight in the desired solution for small positive ε.
Indeed it is shown in [3] that all characteristics of the perturbed problem with stability (i.e. with extra side condition $x(\infty) = 0$) converge to the characteristics of the original problem with stability.
However, there proved to be no such connection between the original problem without stability and its perturbed counterpart ([3, Remark 3.4]).
The explanation for this and the answer to a related question: What is the limit of the optimal cost for the cheap control problem without stability? will be presented in this talk.
It will be shown that a new type of control problem plays a central part. This new control problem requires "partial" stability to be imposed on the optimal state trajectory and therefore it is to be expected that the corresponding cost will lie between the optimal cost without and with stability, respectively. Indeed this is the case and, moreover, this newly defined optimal cost turns out to be the limit of the optimal cost for the perturbed problem without stability.
In addition, the corresponding perturbed optimal input and state trajectory will tend (in distributional sense, see [3]) to the optimal input and state trajectory for the new control problem (if the latter are unique).
Also, an interpretation of the new type of optimal cost is presented in terms of a certain solution of the dissipation inequality ([4]). Thus, both the optimal cost with stability and the newly defined optimal cost and the optimal cost without stability are solutions of this inequality ([4], [1], [2]).

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Partial pole and zero displacement by cascade connection

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In linear systems theory one often encounters the following problem: given a transfer function W one wants to shift part of the poles and zeros of W by a cascade connection with a function R, keeping the McMillan degree $\delta(WR)$ of WR as small as possible.

We consider here the case of a regular square matrix function. By a Möbius transformation we can always assume that $W(\infty)=I_m$. More precisely, let $W(\lambda)=I_m+C(\lambda-A)^{-1}B$ be a given rational matrix function, with no poles and zeros on a given positively oriented closed contour Γ in the complex plane. By γ_+ we shall denote the region inside Γ, by γ_- the region outside Γ. Let P, respectively $P^\times$, be the spectral projection of A, respectively $A^\times=A-BC$, corresponding to the eigenvalues in γ_+. We define the γ_+ - *spectral triple* of W by

$$\tau_+=\{(C|_M, A|_M),(A^\times|_{\operatorname{Im} P^\times}, P^\times B), P^\times|_M : M\rightarrow \operatorname{Im} P^\times\},$$

where $M=\operatorname{Im} P$. The triple τ_+ contains all information concerning the poles and zeros of W in γ_+.

The problem we consider is the following: given an open set Ω with $\Omega\subset\gamma_-$, find all rational functions $R(\lambda)$ such that

$$W_1(\lambda):=W(\lambda)R(\lambda)$$

has the following properties

1) $W_1(\lambda)$ has all its poles and zeros in $\Omega\cup\gamma_+$,

2) the γ_+-spectral triple of W_1 is τ_+,

3) the McMillan degree $\delta(W_1)$ of W_1 is as small as possible,

4) $W_1(\infty)=I_m$.

Formulas for all solutions R will be given, as well as formulas for the corresponding functions W_1. Our solution is based on our recent study of interpolation problems for rational matrix functions. Special cases of this problem have been considered before by P. VanDooren.

A DISCRETE TIME SELF TUNING COMPUTED TORQUE CONTROLLER FOR ROBOTIC MANIPULATORS.

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ABSTRACT

A discrete time self tuning computed torque controller is designed for robotic manipulators. It is suitable when the physical (barycentric and friction) parameters are (at least partially) not known by the user. This algorithm is more refined than the discretization of continuous adaptive computed torque controllers.

It is based on two non linear discrete ZOH models of manipulators which are derived using the "exact" discretization of non linear systems proposed by Monaco and Normand-Cyrot.
The first is linear in the parameters and is used as a basis for on line parameter estimation. The second one is linear analytic and is used for the design of a "Predictive controller".

Finally, the parameter estimation algorithm and the predictive computed torque controller are combined to produce an explicit self tuning controller.

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A Workstation for System Identification

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Abstract :

A Workstation, based on a SUN computer, specifically designed for System Identification is presented. The station is extremely user-friendly since all the manipulations and interactions with the user are performed through a mouse-window oriented dialogue.

All the complex tasks of Identification are available including validation tools while graphical results are displayed at the time they are obtained. An automatic archivage of the session is performed allowing the user to obtain a summary of his work under the form of a well organized and easy to read printed copy of the results or to re-enter an old session that was temporarilly stopped.

Finally, it is possible to ask the Station to class the models from the best one to the worse according to some list of criteria, leading to the implementation of an Expert System to which the user can pass the deal.

A Differential-Geometric Approach to Approximate Nonlinear Filtering

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Abstract
The nonlinear filtering problem leads to a complicated stochastic partial differential equation: the DMZ-equation. Here an approximation method is suggested that is based on the differential geometric approach to statistics (cf. e.g. [Ama 85]). Consider a differentiable manifold of densities. The solution of the DMZ-equation will in general not remain within this manifold. However, if one projects the r.h.s. of the DMZ-equation orthogonally, using the Hellinger metric, onto the tangent space of the manifold, the solution of the resulting stochastic partial differential equation will lie on the manifold, (if one uses the McShane-Fisk-Stratonovich form of s.d.e.'s).

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Numerical aspects of tidal filtering problems

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Kalman filtering has turned out to be a powerful new tool for tidal prediction (Ten Brummelhuis, De Jong and Heemink 1984, Heemink 1986). This stochastic dynamic approach is based on the partial differential equations that describe the tidal flow in shallow waters. Using a finite difference scheme, a detailed numerical model is obtained. In order to employ Kalman filtering for the identification and prediction of tidal flow, the deterministic model describing this water movement is embedded into a stochastic environment by introducing a system noise process. In this way it is possible to take into account the inaccuracies of the underlying deterministic system. By using a Kalman filter, the information provided by the stochastic dynamic model and the noisy water-level measurements taken from the actual system can be combined to obtain an optimal estimate of the system. By employing a Kalman filtering procedure, the data assimilation problem of incorporating measurements into a numerical tidal model can (finally) be solved.
In the lecture we shall concentrate our attention on the numerical aspects of this large scale filtering problem. Firstly, the effects of the finite difference approximation on the filter performance will be discussed. Secondly, we shall pay attention to the numerical robustness of the various algorithms that have been implemented to solve this special filtering problem.

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A deterministic approach to approximate modelling

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Abstract

In this talk we will discuss some properties of a deterministic predictive procedure for time series modelling. In particular we will pay attention to consistency of the procedure. By this we mean that the model identified by the procedure converges to an optimal approximation of the system which generates the data, in case the number of observations tends to infinity. Finally we will illustrate this deterministic approach to time series analysis by means of some examples.

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Observer based optimal control strategy applied to a coal fired Benson boiler.*

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The application of multivariable optimal control concepts to Benson steam boilers is studied in order to meet increasing demands on e.g. process fluctuations or the rate at which the output power can be changed. The control of the output variables is of high importance in situations where the steam boiler is connected to electric power systems, for which frequency and amplitude of the generated voltage must be kept constant.

Linear model and state reconstructor.

A nonlinear boiler simulation model is used to generate step responses for relevant inputs for a certain set of operating conditions. The approximate realization technique has been modified to be able to use longer response sequences with the same dimensions of the Hankelmatrix. These maximum dimensions are machine dependent. As an example it can be stated that a Hankel matrix of dimensions 240 x 240 has been used to construct a linear model for a 1600 sample step response of a system with 5 inputs and 6 outputs.
A low order approximating model is then taken as the basis of a state reconstructor. This state reconstructor can be extended with integrating action to make it insensitive to static process state disturbances or time varying process dynamics.

LQR controller.

The reconstructed states will be connected to an LQR controller to stabilize the process. A servo control loop will also be applied to handle the required setpoints for process outputs.

This optimal control strategy will first be applied to the control of the steam temperature and in a later phase to other control loops of the boiler installation.
The adaptation of the state reconstructor and controller under changing operating conditions will have to be studied.

* This research was sponsored by PEO and conducted under the supervision of Stork Ketels B.V., Hengelo.

Orthonormal Polynomials with Shift Structure: Extensions and Transformations.

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The set of orthogonal discrete Laguerre polynomials $\{\psi_i(k)\}$ forms a basis for $\ell_2[\mathbb{N}_0,\mathbb{R}]$, with $\sum_k \psi_i(k)\psi_j(k)=\delta_{ij}$.

They can be described as the impulse responses of the transfer functions

$G_i(z^{-1})=\sqrt{1-\xi^2}\,\dfrac{(z^{-1}-\xi)^i}{(1-\xi z^{-1})^{i+1}}$,where $\xi\epsilon(0,1)$ is the one degree of freedom, to be seen as a time scaling parameter.

For every $f(t)\ \epsilon\ \ell_2$ we can define the transformation $f(t)=\sum_k F_k\psi_k(t)$

with $F_k=\sum_t f(t)\psi_k(t)$ and $\Sigma f(t)^2=\Sigma F_k^2$.

A nice and useful property is the so called shift structure:

Denote by $\underline{\Psi}_n(k)=[\psi_0(k),\psi_1(k),..\psi_n(k)]^T$, then the following relation holds for all k:

$\underline{\Psi}_n(k+1)=P_n\,\underline{\Psi}_n(k)$, with P_n a known lower triangular matrix, independent of k.

This property makes it possible to transform linear systems:

Let $\{u(t),y(t)\}$ be an i/o–pair of a linear system S_t with transfer function $G(z^{-1})$ and denote by $\{U_k,Y_k\}$ the Laguerre coefficients. Then $\{U_k,Y_k\}$ is an i/o– pair of a system S_L with transfer function $G([\pi(z^{-1})])$, where $\pi(s)=\dfrac{\xi+s}{1+\xi s}$.

On state space level this leads to : (with $R=[I-\xi A]^{-1}$),

$S_t=[A,B,C,D,x_0]\ \rightarrow\ S_L=[AR\ ,\ \sqrt{1-\xi^2}\,RB\ ,\ \sqrt{1-\xi^2}\,CR\ ,\ D+\xi CRB\ ,\ \sqrt{1-\xi^2}\ x_0]$.

Properties like stability, observability, controllability and singular values are invariant under this transformation.

There are several ways to use this theory in an identification context.
We will show how this particular set of orthonormal functions can be generalized, using the singular vectors of an n–dimensional Hankel–matrix, considering these as a set of n orthonormal functions and extending this set to an infinite set with a shift structure.

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Flexible controller structures for optimal control

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Introduction

Chemical plants are operated under changing conditions. Some of these variations can be substantial. Different optimal plant settings will result after performing optimization for these conditions. In this study the implications of plant optimization for controller set points and controller structure are treated.

Plant-wide control

Plant-wide optimization is performed using models under stationary conditions in a chemical plant consisting of a reactor and three distillation columns. The optimization is performed hierarchically at two levels. At the higher level flows between the process units and their concentrations are determined optimally according to a rough model. At the lower level the flows and concentrations are fixed input variables for an optimization at process unit level using detailed models. The quality of the optimization at the upper level can be judged using the Lagrange multipliers for the fixed input variables at the detailed optimization level.

Optimal set points and constraints

The result of the plant-wide optimization are set points for controllers. Usually at least one constraint which depends on the process environment is active during optimization. Some of these contraints, e.g. distillation column pressure, are setpoints of controllers. The process variable must then be kept at an extreme (minimum column pressure) and will be changing continually as a result of minor process disturbances. Other constraints, e.g. flooding of trays in a distillation column, are not as straight-forward. A constraint control algorithm has to be used to implement the optimal control strategy. This analysis shows the need for different controller structures due to vast changes in the process environment.

Changing controller structures in a distillation process

The effect of changing controller structures on a distillation process is examined in a computer simulation of the process. For this purpose, a non-linear dynamic model of a distillation column has been developed, representing the behavior of the trays, the reboiler, the condensor and the accumulator.

Special attention is paid to the phenomenon of bumpless transfer, when changing from one controller structure to another. Result show that change-over can be carried out without severe transients of process variables.

Conclusions

Simulation studies have demonstrated that plant-wide optimization can be carried out using a rough model of the plant, supported by detailed models of the units. When certain disturbances force a change of controller structure, it can be activated in a bumpless way. The results encourage practical applications.

INPUT-OUTPUT DECOUPLING WITH STABILITY FOR HAMILTONIAN SYSTEMS

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It is well known that the nonlinear (scalar)inputs-(scalar)outputs decoupling problem is solvable if and only if the decoupling matrix has full rank everywhere. Furthermore, with the aid of this decoupling matrix one can easily construct a large class of decoupling feedbacks, which all have the property that they decouple the system into m linear input-output systems (with m the number of inputs and outputs), together with an unobservable nonlinear system (which actually is the *maximal* subsystem that can be made unobservable, see [1] for references).

In this lecture we will deduce as a preliminary a result on the canonical form for general input-output decoupled systems, which is of interest on its own.

After this we will tackle the input-output decoupling problem with stability for Hamiltonian systems.We consider the same class of decoupling feedbacks as indicated above. In [3,4] it was shown that in the Hamiltonian case the remaining unobservable nonlinear system is a *Hamiltonian* subsystem of the original system; in fact its dynamics are governed by a Hamiltonian function $\bar{H}$, which is simply obtained by restricting the original Hamiltonian function H (energy) to a symplectic submanifold which forms the state space for this unobservable nonlinear system. It follows that these unobservable dynamics are at most stable, but never asymptotically stable. The main result of this lecture states that if the Hamiltonian $\bar{H}$ has a strict (local) minimum in the equilibrium point- a condition which can easily be checked, and which forms a sufficient (and in many cases generically also a necessary) condition for stability of the unobservable dynamics-, then by making the linear input-output systems asymptotically stable by feedback the whole closed loop system becomes stable.

We note that in the approach taken in this lecture, *asymptotic* stability of the input-output decoupled Hamiltonian system can only occur if the maximal unobservable system is zero-dimensional. Motivated by [2], we will give some starting points for further research on the input-output decoupling problem with asymptotic stability for Hamiltonian systems.

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An application of suboptimal minimum variance control and filtering.

by

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Abstract

The following control problem involving nonlinear differential systems and continuous-time (nonlinear) measurement equations including noise will be considered. The objective of the control is to minimize the variance of one of the state variables at a fixed final time. A practical limitation for this combined filtering and control problem is that the corresponding algorithm must be on-line, such that it results in a closed-loop controller, and it must be implemented on a computer. A suboptimal controller has been derived by an application of an assumed certainty equivalence design and by choosing, at each time instant, the control in such a way as to maximize the descent of the corresponding component of the covariance matrix (resulting from a nonlinear filter).

A well-known example is the bearings only measurements problem. The underlying differential equations and measurements equations with respect to suitably chosen model variables have right hand sides which are guadratic in the arguments. If doppler shift measurements are included another system with the same property results. Special attention is paid to the case of hardly known initial values, yielding a small initial information matrix. A heuristic application of the power series method gives a plausible result in this case. Also, the combination of a linearization and an inverse Kalman filter will be considered.

Up to this point stochastic integration theory has not been used. By using Itô integration theory the Itô integral equation of the information matrix has been derived. To test the theoretical results, a few filters and the above mentioned control were simulated by numerical integration of the relevant Itô differential equations.

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General results on the McMillan degree and the Kronecker indices of ARMA- and MFD models

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Abstract

ARMA- and MFD models are commonly used for modelling the I/O behaviour of linear finite dimensional time-invariant, time-discrete systems. Well-known and standard results exist on the McMillan degree and the left Kronecker indices of MFD models: the McMillan degree of a proper MFD $P^{-1}(z)\,Q(z)$ is equal to $\deg\det P(z)$ if $P(z)$ and $Q(z)$ are left corpime, and its left Kronecker indices are equal to the row degrees of $P(z)$ if $P(z)$ is additionally row-reduced. For ARMA models such results however do *not* hold (consider e.g. MA-models: i.e. $A(d) \equiv I$) .

The situation is however less negative than these results may suggest. We will show that the McMillan degree of general ARMA- and MFD models is equal to the *pole-zero excess* of the matrix consisting of the polynomial factors (i.e. $[A(d) \vdots B(d)]$ resp. $[P(z) \vdots Q(z)]$).

Furthermore the left Kronecker indices are equal to the row degrees of this matrix if and only if it is row-reduced and irreducible. For left coprime ARMA- and MFD models the McMillan degree and the left Kronecker indices are related to the determinantal degree and the row degrees of a suitable submatrix of the polynomial factors. Under certain (necessary and sufficient) conditions this information can even be inferred from the denominator matrices in the ARMA- and MFD models.

Finally a rank test is presented for actually computing the McMillan degree of left coprime ARMA- and MFD models.

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MODELLING THE TREATMENT PROCESS OF BRACHIAL PLEXUS INJURIES: THE PLEXUS SYSTEM.

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The rehabilitation of brachial plexus injuries comprises a complex of activities in many different fields. This multidisciplinary approach necessitates a good information exchange among the treatment team members. However, even then it is very hard for the team members to get a coherent view of the entire process, since the amount of data to be dealt with is very large, and covers a broad field of expertise. A preliminary study of the rehabilitation of brachial plexus injuries has shown that very often this causes a non-optimal treatment (Jaspers, 1986). In order to improve the treatment, the PLEXUS support system is being built, using system identification to obtain a patient model that predicts the future state of the patient (prognosis). Although the amount of patient data available is rather small, results obtained thus far indicate that the recovery of the patient can be predicted by simple first-order models (Happee, 1986). However, further analysis of the characteristics of the process has shown that an important cause of the poor treatment results is a lack of good diagnostics (Jaspers, 1986). This means that the system's initial state, i.e. the possibilities for recovery, is often unknown. Of course, the prognosis is very sensitive to this. Therefore, techniques based on artificial intelligence are applied to improve diagnostics and treatment planning, previous to aiding the prognostics. Two expert systems have been built, consisting of over 1100 rules each. Both modules perform well, yielding 85% correct advices concerning diagnosis and treatment plan, when compared to the human expert. This is a significant improvement compared to 50% sufficient diagnoses in general practice (Jaspers, 1987). Nevertheless, expert systems have a certain disadvantage also. Since the aim of expert systems is to lay down experts' knowledge about a certain problem area, the best to be achieved is to approximate their results as well as possible. This means that, in contrast to other modelling techniques, an expert system will never present new information about the domain. This is particularly a problem for the prognostic and treatment evaluation parts of the system, since knowledge is still rather limited in these fields. Therefore, as mentioned earlier, a patient model, based on measurements of a number of patients, will be used to give better insight in prognosis and treatment effect. However, this approach presents some important disadvantages also. First of all the model has no physiological significance, which will hamper the acceptability. Secondly, a lot of data is required in order to derive a model. In the PLEXUS system the first problem is overcome by incorporating the models in expert systems. These systems contain knowledge about the treatment process and therefore they are able to explain their reasoning. Furthermore the problem of data acquisition, which tends to be a bottleneck in medical support systems, may be solved by incorporating database and reporting facilities. An important aspect of PLEXUS is that it will aid in all stages of the treatment process and that it integrates different modelling approaches in the same system to overcome the problems posed by each individual method:
- Expert systems for diagnostics and treatment planning.
- Patient models for prognostics and treatment evaluation.

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Direct Model Reference Adaptive Control
of Multivariable Systems

by

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Summary

Direct or implicit model reference adaptive control algorithms for multi-input multi-output systems are developed. These algorithm do not require either satisfaction of the perfect model following conditions or explicit parameter identification. The first algorithm ensures asymptotic stability of the output error provided that the controlled plant is "almost strictly positive real", i.e. there exists a positive definite static output feedback (unknown and not needed for implementation) such that the resulting closed-loop transfer function is strictly positive real.

The second algorithm uses parallel feedforward and the stabilizability properties of systems in order to satisfy the "almost positivity" condition. The feedforward configuration may be stationary if some prior knowledge is given or adaptive. In this manner, simple adaptive controllers can be implemented for a large number of complex control systems, without requiring prior knowledge of the order of the plant or the pole excess.

Appplications of Direct Model Reference Adaptive Control

by

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Summary

Direct model reference output adaptive control procedures have been applied to a wide class of examples including large structual systems, DC Motors, physiological systems, and flight controllers. Such problems are shown to benefit from adaptive control because of their inherent uncertainties and/or variations. Illustrative applications are presented showing how the sufficiency conditions and the relevant weighting parameter selection are incorporated into the design process. Where appropriate, results are used to show the benefits from adaptive control and in particular the advantages of using direct adaptive control.

SIMSAT

Simulation Package for Flexible Beams

by

Martin H. Klompstra* and Jan Bontsema**

In order to study the dynamical behaviour of a system or a system together with a controller one often uses a simulation package. In the finite dimensional case there are a lot of general purpose simulation packages. However for systems described by partial differential equations no such general purpose package exists. In order to study the behaviour of some models for a flexible beam and to study the effect of controllers on such models, [2], [3], a very user friendly simulation package was designed, [1]. In this talk we will discuss the program and we will give a demonstration on a personal computer.

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Modelling and Control of a

Flexible Robot Link

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ABSTRACT

When modern industrial robots are compared with human beings, a great difference can be noticed between the ratio of the weight of the manipulator and that of the payload. Human beings can handle loads up to 50 percent of their weight, while a robot manipulator can handle only 5 percent of its weight as a maximum.

The reason why industrial robots are so heavy, is due to the fact that stiff (and therefore heavy) constructions are used in order to achieve a high accuracy with a relatively simple control algorithm.

By making the links of a robot lighter (and therefore less stiff), there will appear vibrations in the links. Therefore the control algorithm will be much more complicated. In this paper some controllers for a flexible beam will be given.

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INTERACTIVE SYSTEM IDENTIFICATION WITH PRIMAL

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Abstract:

The software package PRIMAL assists the user in the generally difficult task of estimating a dynamical model for an industrial process. This contribution will discuss the interactive approach to system identification supported by the package and then focus on the identification methods implemented in PRIMAL (Recursive Prediction Error Methods, Bootstrap-IV, Approximately Optimal IV, Impulse Response Estimation, Guidorzi's method, Direct estimation in the Frequency domain, Extended Kalman Filtering). The performance of these methods on a number of practical processes will be compared.

System Identification - A status report

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System Identification concerns the problem of building mathematical models of dynamical systems, based on observed data. The subject has matured to a well established field, with a well understood basic theory, as well as basic principles. Efficient algorithms have been developed, and several interactive software packages exist. Many industrial applications have also been performed.

In this seminar the basic principles and techniques are investigated. Special attention is paid to the relationship between different methods, such as time domain and frequency domain methods.

The discussion is focus on the situation of the user: What choices does the user have when he/she approaches a practical identification problem, How should these choices be made, so as to secure a good and useful model for the purpose in question. Experiment design, as well as the choice of several design variables within the identification problem is discussed from this perspective.

The role of interactive software for the system identification problem is also discussed, as well as issues for future research and unsolved problems.

Adaption and Tracking in System Identification

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The fact that a system may have properties that vary with time or with operating point is of prime concern in model building. To continuously update a model so that it constantly is based on recently available information is in many applications necessary for good operation, signal processing and the like.

In the system identification literature techniques for continuously updated models are called recursive identification methods. In this seminar we describe some basic principles for recursive identification. The focus is how to achieve the best possible adaptation and tracking properties, in order to cope with the time variation of the system.

Both old and new techniques to deal with this problem are described. Various conditions are studied, such as slowly and constantly varying systems, piecewise constant systems with abrupt transitions, systems shifting between a finite number of different dynamic properties and so on.

Special attention is paid to the description in the frequency domain of the quality of the estimated model, and to discuss how to choose certain design variables in the tracking and adaptation features, so as to minimize the mean square error in the description.

System technology in rehabilitation of people with a missing or paralyzed arm.

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Activities at the Delft University of Technology in the field of rehabilitation were initialised by the thalidomide affair. It started in 1967 with activities to improve components in existing armprostheses. A close cooperation was established with a number of rehabilitation centres. Presently two groups within the control laboratory are active in the field of rehabilitation: the "Instruments" group which is involved in the design of prostheses and orthoses for upper limbs, and the "Man-Machine Systems" group which is active in the informational aspects, such as evaluation studies, modelling of rehabilitation processes and of biomechanical systems.

It will be pointed out that the design of an armprosthesis is only partly a control problem. Definition of design specifications is an iterative process. Priorities can only be obtained by extending the boundaries of the system under consideration.

Extension of the system boundaries is also specific for the project on aids for people with a paralysed arm. A paralysed arm is often caused by a motorcycle accident which in some cases results in a rupture of the nerves controlling the arm muscles. Sometimes, at least partial recovery is possible. In these cases an orthosis may be a useful training device. For some types of rupture, however, the paralysis is permanent. In those cases some control over the upper arm may be restored by fixing the upper arm to the shoulder blade and by providing the arm with an elbow orthosis. The operation is irreversible and the choice of the fixation angles is rather crucial.
Unfortunately, the diagnosis is not always clear at the beginning of the rehabilitation process, so that a decision whether to perform an operation or not is often postponed.
Therefore, what initially started as a project to evaluate arm orthoses resulted in two other projects namely an expert system for diagnosis and treatment of brachial plexus injuries, and a kinematic model of the schoulder girdle.

Indoor Temperature Control using Predictions*

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The work described is part of the research project to develop and apply energy saving control strategies in buildings. One of these strategies is the predictive control strategy. The goal of this strategy is to maintain a required comfort in a building with a minimal energy consumption by taking appropriate actions based on a prediction of the indoor temperature of the building.

The indoor temperature at a certain time is determined by the total thermal load of the building, the building dynamics in consequence of the mass of the building and the behaviour of the climate installation. The thermal load is divided into two independent components. The load caused by internal energy sources (both people and machines) and the external load caused by the outdoor climate. The approach is to predict the indoor climate by means of a dynamic model of the building, which has the outdoor climate,the internal load and the cool/heating load as input signals. With use of this prediction model it is then possible to seek for the minimum required cool/heating load to meet a required comfort under the predicted circumstances (outdoor climate and internal load).

A weather predictor has been developed. A self adaptive model has been chosen which predicts the required signals from the prediction of the national meteorological institute and from local measurements. The building model is also a self adaptive model, because it is impossible the generate an accurate model from the physical proportions of the building. The internal load is estimated from the daily pattern of prediction errors. The parameter estimation of both weather models and building model is done with a recursive least squares parameter estimator.

The weather predictor has been tested with weather data of 1972. Hourly series of 24 hours in advance have been generated with the predictor. The results are promising for solar radiation, temperature and humidity. The self adaptive building model has been tested by means of a reference building simulation based on equations describing the physical behaviour.

An ad-hoc control strategy has been developed and is tested at the moment.

Also the energy savings and comfort consequences will be investigated by comparing this system with a reference control system.

The models are quite simple and requires, except for a sunshine prediction of a national meteorological institute, only local measurements.In addition with local self adaptive controllers for the HVAC units a rather automatic and intelligent control system is created.

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FUTURE SCENARIOS FOR TRAVEL DEMAND IN THE NETHERLANDS

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Abstract

The uncertainties concerning future developments in mobility patterns are anxiously great. There is a strong quest for models giving information on possible impacts of policy measures upon transport behaviour, but the ability to give adequate answers is very much hampered by existing uncertainties concerning the social and economic developments that are likely to occur.
Research that addresses developments in mobility deals with the functioning of society as a whole. It is clear that such a research item is not easy to handle and that often simplifying assumptions are necessary to be able to analyse developments in a tractable way. Under contract of the Dutch Ministry of Public Works the Traffic and Transportation Department of the TNO Institute of Spatial Organisation has developed a simulation model that tries to describe medium term macro developments in the Netherlands.
The model, called the Mobility Explorer, is presented in more detail. In the model the number of passenger kilometers by mode and trip purpose are related to developments in population statistics, car ownership rates, employment rates, income variables, public transport fares, variable car costs and service levels of public transport. The model can easily handle several scenarios for the exogeneous variables. Uncertainties in model parameter values can be dealt with using a Monte Carlo technique. The main "control" variables in the model - that is, control within the transportation field - are the public transport fares and the variable car costs (taxes).
In the presentation the following subjects will be highlighted: the model structure, the uncertainty calculations, the results of a validation study and some recent applications.

Symbolic generation of dynamic and identification models for robots : linearity with respect to barycentric parameters

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Various problems in robotics require the computation of the dynamical model of the robot which relates the generalized forces transmitted by the joints and the generalized coordinates (q_i). This dynamical model contains the physical characteristics of the bodies (links) constituting the robot. Therefore, a good knowledge of these parameters is absolutely necessary. This is not trivial for the parameters related to the mass distribution and thus naturally leads to the problem of the identification of these parameters [1]. The latter is treated in a companion paper [2] which presents a method based on the measures of the reactions between the robot and its base-plate.

We show, in this paper, that the dynamical and the identification model have the same structure and - often noted "a posteriori" as a fact [3] - that these models are linear with respect to the parameters of mass distribution if barycentric quantities are used. In addition, all the barycentric parameters occuring in the dynamical model appear explicitly in the identification model. However, it should be noted that this linearity is valid only if the geometrical lengths of the links of the robot are supposed to be known.

In order to emphasize these properties, we have, in the first part of this paper, written the equations of a multibody system in a general vectorial form by means of a generalized d'Alembert principle.

In a second part, we describe the programme ROBOTRAN which provides the dynamical model and the identification model for a tree-structured manipulator in a symbolic form. In other words, ROBOTRAN deals with mathematical expressions by means of pointers (PASCAL programming language) and prints the resulting equations in a literal form (character strings). The main purpose of this programme is, of course, to generate these models but in such a form that the barycentric parameters (and/or their combinations) are strongly emphasized. The models are therefore not necessarily optimal as regards the number of arithmetical operations.

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Applications of systems theory in real-time river flow forecasting

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DELFT HYDRAULICS is developing an operational system for real-time river flow forecasting and flood control. This presentation aims at highlighting some systems theoretical problems that have been identified. Two dynamical processes have been modelled, the rainfall-runoff process and the process of flow propagation through the network of open channels. Flow forecasts form the inputs for a control algorithm for operation of structures, like weirs and gates.

The rainfall-runoff proces is a strongly non-linear MISO-system that can be modelled using either hydrodynamic laws, either a certain concept on the systems behaviour, or an adaptive ARMAX approach.
Cf [1] the conceptual model 'Sacramento' is embedded in a first order EKF. Observability problems can be expected in practical applications. A tentative comparison with the adaptive ARMAX algorithm as described in [2] is made.

The flow propagation process can also be modelled using either hydrodynamic laws, either a certain concept of the system, or an adaptive ARMAX approach. Cf [3] a first order EKF is derived for the hydrodynamic equations of St. Venant. Computational problems can be expected in practice due to the dimensions of the state vector. Partitioning [4] or decomposition of the filter is necessary. Perspectives of the ARMAX approach are discussed.

Finally a few remarks are given on the applicability of an LQG algorithm in the flood control problem .

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A PNEUMATIC CONTROL CIRCUIT FOR HAND PROSTHESES

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At Delft University of Technology a new hand prosthesis for children is under development. This prosthesis is myo-electrically controlled and pneumatically powered in an attempt to overcome the major disadvantages of the commercially available myo-electrically controlled, electrically powered hand prosthesis, i.e. prosthetic weight is high, operating speed is low, the system is vulnarable and its size prohibits fitting it to patients with a long fore-arm stump.

Carbondioxide was chosen as the working fluid. In order to minimize prosthetic weight a low gas consumption is of prime importance. Therefore the operating cycle of the hand was split into two parts: a prehension phase and a pinching phase. In the prehension phase the hand can be opened and closed. As soon as the thumb contacts the fingers of the hand or an object the mechanism is automatically switched to the pinching phase. In the pinching phase a force is exerted between fingers and thumb. To resist the reaction forces a locking mechanism has been provided.

This solution requires three pneumatic motors to be driven sequentially. These motors are of the piston-cilinder type with O-ring seals.

A logical circuit has been designed to ensure the desired operation. To minimize the number of electric-to-pneumatic converters the logical circuit has been chosen to be pneumatic. It contains four mechanically actuated two-way normally-closed valves and three check valves. Both types of valves have been especially designed.

A prototype of the prosthetic system was build.

To get a good understanding of the performance of the system and to predict the influence of future changes a mathematical model of the system has been built with the help of SIMBOL, an interactive computer simulation program. The model comprises variable pneumatic volumes, working fluid compressibility, piston frictions and valve restrictions. Interactions between the different circuits are part of the model.

An Adaptive LQ Controller for a Class of First Order Systems

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ABSTRACT

We consider the problem of controlling a linear time-invariant finite-dimensional system adaptively according to a quadratic cost-criterion. It has been shown ([1]) that for the class of adaptive control algorithms based on certainty equivalence, there is a conflict between identification and control, in the sense that, due to the identification in closed-loop, the asymptotic behavior of the adaptively controlled system will be sub-optimal with respect to the criterion.

The lack of excitation caused by closed-loop identification could be avoided by injecting an external signal into the system. The disadvantages of this method are that external signals can be annihilated by unpredictable internal signals and that zero-regulation of the output is impossible.

We propose an adaptive control algorithm for the class of first order systems, based on dual control. The control consists of a certainty-equivalence part and an excitation part. The excitation is proportional to the output and hence zero-regulation of the output is possible. Also the excitation part contains a design-parameter which enables us to approach the optimal behavior arbitrarily close.

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Local Stochastic Modelling to represent fine scale heterogeneities in coarse grid numerical models for one-phase flow through porous media

by

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ABSTRACT

Reservoir simulators are used for the numerical simulation of oil and water through porous rocks. The reservoir flow simulators are based upon mathematical models which are defined on the scale of the grid used in the numerical computations. The permeability exhibits rapid and irregular spatial variations at length scales much smaller than the grid blocks used in the reservoir simulations.

A model is presented, which can be used on the grid scale and which accounts for these fine-scale heterogeneities. To this end the fine scale permeability is modelled as a random field, rather than a deterministic quantity. The step from the fine scale to the grid scale comes down to finding the mathematical expectation of the inverse of the stochastic partial differential operator, used in the flow description on the fine scale. This is achieved by transforming the stochastic partial differential equation with appropriate boundary conditions to an integral equation with random kernel and finding an approximate solution of the integral equation.

As expected, the permeability on the grid scale depends upon the statistics of the random field permeability and on the nature of the flow on the fine scale.

Examples are given, including Monte Carlo simulations to substantiate the obtained results.

Input-output representations for A.R.-models

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Let the behavior of a discrete time, linear, time invariant,finite dimensional system $\Sigma = (\mathbf{T},\mathbf{R}^q,\mathcal{B})$ be given as the solution of an A.R.-equation:

$$\mathcal{B} = \{w \in (\mathbf{R}^q)^{\mathbf{T}} \mid R(\sigma)w = 0\}.$$

Here $\mathbf{T} = \mathbf{Z}$ or $\mathbf{N} \cup \{0\}$, $R \in \mathbf{R}^{g \times q}[s]$ and σ is the forward shift: $(\sigma w)(t) = w(t+1)$.

In this talk the following question is treated:
Find (in a numerically reliable way) a permutation matrix T of size q, and polynomial matrices P and Q such that

- $R = (Q,-P)T$;
- det P is not identically zero
- $P^{-1}Q$ is a proper rational matrix.

It is well known that this problem can easily be solved if R is row reduced. If, however, R is not row reduced, then one has to find first an equivalent A.R.-equation with a row reduced R'. Although recently a numerically reliable way to solve this problem has been presented [1], it still is a cumbersome and time consuming affair. Using the construction of a minimal polynomial basis for the kernel of R, as de scribed in [2], yields a good alternative.

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A KINEMATIC MODEL OF THE SHOULDER GIRDLE.

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Patients with a permanent paralysis of the upper arm muscles as a result of a brachial plexus injury sometimes undergo a shoulder arthrodesis. After such an orthopaedic operation in which the humerus and the scapula are fused together, the subject will be able to actively position the humerus again by moving the scapula. Thus, combined with an elbow orthosis, the shoulder arthrodesis leads to some function restoration of the subject's arm. However, the destruction of the shoulder joint and the uncertain result of the arthrodesis impede the patient's decision to undergo an operation or not. Hence, it is desired to predict the positive and negative effects of the arthrodesis reliably. Therefore a 3D model of the shoulder girdle will be developed.
The shoulder girdle consists of two bones, i.e. the scapula and the clavicle which are connected by the acromioclavicular joint. Via the sternoclavicular joint between the sternum and the clavicle, the shoulder girdle is bound to the trunk. Basically, the function of the shoulder girdle is to provide the arm a solid base for function and to enlarge the mobility of the shoulder joint. Therefore the main part of the scapula, i.e. the socket of the shoulder joint, has to be able to point in a large number of directions. A system of 7 muscles surrounding the scapula acts as the motor of the shoulder girdle, whereas the ligaments near the joints restrict the rotations of the bones.
The first step in modelling this complex spatial mechanism is the development of a 3D kinematic model. In this model, the shoulder girdle structure is divided into finite elements according to the kinematical application of the finite element method which is developed by the laboratory of Technical Mechanics of the Delft University of Technology. The bones of the shoulder girdle are modelled by means of one or more beam elements, whereas the joints are composed of one or more hinge elements. In behalf of the shoulder girdle model, two elements have been developed: the cable and surface elements representing, respectively, the ligaments and the thorax.
The basic assumption of this model is that the mobility of the bones is restricted on the one hand by the extracapsular ligaments near the joints and on the other by the thorax. In addition, it is assumed that during all motions the medial border of the scapula always will follow a part of the thorax, the so-called scapulothoracic wall. Based on former measurements, this wall is modelled as an ellipsoid of which the center is located at the level of the eighth thoracic vertebra, whereas the length of the three axes can be derived from the outside depth, width and heigth of the thorax. Modelled in that way, the shoulder girdle can be considered as a mechanism with four degrees of freedom. The ligaments only play a part in the system when they become taut. As soon as one of the ligaments is tightened, however, the number of degrees of freedom will be diminished by one.
After the validation of this model structure, the model will firstly be verified by measuring the shoulder girdle motions and the humerus motions, respectively, before and after the shoulder arthrodesis. After that, it will be possible by means of simulations to calculate the optimal fixation position of the humerus with regard to the scapula from the present mobility of the shoulder girdle before performing the shoulder arthrodesis.

IDENTIFICATION OF BARYCENTRIC PARAMETERS OF ROBOTIC MANIPULATORS FROM EXTERNAL MEASUREMENTS.

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Abstract

This paper proposes an estimation procedure for the barycentric parameters of a robot, using only external measurements (reactions of the robot on the bedplate and generalized positions, velocities and accelerations) which are independent of the articular forces (actuators and friction effects). The identificability conditions are discussed numerical and experimental results are also given.

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Keywords:

System identification, Industrial processes

A GRID SEARCH IDENTIFICATION ALGORITHM

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Abstract:

Most algorithms used for identification do not function very well when applied to some of the data sets that are available in industrial practice. In many cases these data sets are either too short or contain too many disturbances for these methods to converge properly.

This paper describes a robust algorithm based on grid search, which always converges to the best model in a given parameter subspace, provided that the grid points are not chosen too far apart.

Special care has been taken to minimize the number of computations per grid point and to reduce the dimension of the grid by exploiting symmetries in parameter space.

The execution time of the resulting algorithm compares favourably with other methods, such as the 4-step instrumental variable method, for relatively low order MIMO (Multiple Input Multiple Output) systems.

A Central Limit Theorem for Discrete-Event-Systems

One common feature of certain industrial processes is that production lines (plants) have to wait for components of other plants before they can start a new production cycle. If $x_j(k)$ denotes the starting time of the k-th cycle of plant j and if $a_{ij}(k)$ denotes the time-length until the product manufactured by plant j becomes available at plant i then

$$x_i(k+1) = \max\{x_1(k)+a_{i1}(k), \ldots, x_n(k)+a_{in}(k)\}, \quad 1 \le i \le n.$$

Here we study the asymptotic behaviour of $(x_1(k),\ldots, x_n(k))$, for $k \to \infty$, in case the matrices $A_k=(a_{ij}(k))$ are independent and identically distributed. We shall show that $x_i(k)$ is asymptotic normal by using that $x_i(k)$ can be written as the partial sum of a function of an imbedded Markov chain.

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A Concept of State for 2-D Systems

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SUMMARY

In this talk a non-causal concept of state is introduced for deterministic 2-D systems. This concept is based on a Markov-like property which can (in some sense) be viewed as a deterministic version of the global Markov property defined for 2-D random fields. The particular case of autoregressive (AR) 2-D systems is considered and the structure of the equations describing an AR state space system is characterized.

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Time-optimal control for a particular two-link robot

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The time-optimal control for the Vermaat Technics VERAII robot with a horizontal arm with two links and with constraints on the controls is considered.

The influence of the friction on the behaviour of this particular robot is high. Therefore in earlier work [1] an approximate model with two linear uncoupled subsystems (i.e. the upper and the lower link) has been used for determining the minimum-time control. Simulations with this control have shown that the coupling between the two links should not be neglected. The coupling is mainly due to the influence of the controls on both links and not due to the nonlinear terms in the model.

Two approximate linear models have been derived, which take this coupling into account. These approximations agree with modified versions of the Averaged Dynamics [2] and the Time Varying Switching Curves (TVSC) [3] method, which both lead to a model consisting of two coupled linear subsystems. The TVSC method uses such a feedback that the model can be transformed into two uncoupled subsystems. For the robot considered in this paper, the friction terms prohibit this transformation into two uncoupled subsystems. The time-optimal problem for this model has been solved.

In simulations these two methods have been compared with the uncoupled approximation. For this type of robot, the total time needed to steer the arm from one position to another, using these methods, usually is smaller than when the uncoupled approximation is used [4].

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Abstract

ALMOST DECOUPLING AND HIGH-GAIN FEEDBACK IN
LINEAR AND NONLINEAR SYSTEMS

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During the last two decades various decoupling problems have been successfully treated for linear as well as for nonlinear systems. Main tool in solving these problems has been geometric linear control theory and its nonlinear counterpart which surprisingly closely parallels the linear theory. Recently there has been for linear systems a new development due to J.C. Willems, who posed and solved the problem of characterizing those systems for which disturbance decoupling can be achieved approximately with an arbitrary degree of accuracy (dubbed almost disturbance decoupling). Subsequently several researchers, admittedly mainly Dutch, have contributed to the "almost" geometric theory. The present talk is largely concerned with almost decoupling problems for (a class of) nonlinear systems. Although it seems at first sight most logical to generalize the linear geometric tools introduced by Willems to the nonlinear context, it is found that the serious problems encountered can be circumvented by using an alternative approach, which is based, geometrically speaking, on the structure at infinity of the system and on a singular perturbation analysis of the system after the application of high-gain feedback. An appealing feature of the approach is that it yields an explicit parametrized high-gain feedback law for the almost decoupling problem under consideration. This fact, apart from the new perspective it provides, makes the approach also of interest in the linear case.

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Control of discrete events

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March 1988

In this talk a discrete event process is modeled as an extended trace structure $P =< \mathbf{t}P, \mathbf{e}P, \mathbf{c}P >$, with $\mathbf{c}P$ the *communication alphabet* (representing all communicating events of the process), $\mathbf{e}P$ the *exogenous alphabet* (representing all exogenous events) and $\mathbf{t}P$ a set of sequences of these communicating and exogenous events (representing the *behaviour* of the process).

The exogenous events are used to model *own* actions of the process. The communicating events are used to model actions that may be common to other processes and therefore are of interest in communication with other processes.

First a *connection* between two discrete processes is defined resembling a kind of shuffle of the behaviours of the processes, such that common events occur in both processes simultaneously. This kind of connection is known as *blending* in trace theory.

Next a control problem is formulated: given a discrete process P and a lower and upper limit of the exogenous behaviour of P (i.e. the behaviour of P restricted to the exogenous events only), find a second process $R =< \mathbf{t}R, \emptyset, \mathbf{c}P >$ with the same communicating events as P such that in the connection the behaviour restricted to the exogenous events of P lies between the given limits.

Finally a necessary and sufficient condition is given for which a controller can be found. A construction of this process is given also. It turns out that two functions (dependent on P and the limits) have to be computed: if the first function (called the *guardian*) satisfies some condition, then the second function (called the *friend*) gives the controller.

An example will be given to illustrate this theory.

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Control of freeway traffic flow

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In this talk we will consider a control problem concerning freeway traffic. The Dutch Motorway Control and Signalling System [1] installed on several freeways in the Netherlands allows the display of advisory speed signals to influence driver behaviour. One of the goals of this signalling system is to avoid, or at least to postpone congestion on the freeway.

The problem was divided in three parts: first a model has been developed, describing the evolution of the traffic state variables: *density* (number of vehicles per km per lane) and *mean speed.* Next a filter has been derived and tested against simulated and real traffic data. The original filter was modified to achieve satisfactory estimates. Measurement data on traffic speed was shown to be necessary to achieve filter robustness with respect to modelling errors. Finally, a control problem is posed and solved numerically. For this, the effect of displaying advisory speed signals on driver behaviour had to be investigated. This was done using data obtained during experiments with the signalling system in 1983 [3]. These data were provided by the Traffic Engineering Division of the Dutch Ministry of Transport.

In the talk we will mainly discuss the control problem, after a short presentation of the model and of the filtering results. More details on the traffic model may be found in [2]. A report on filtering of freeway traffic flow will appear spring 1988.

These investigations are supported by the Technology Foundation (STW).

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SELF-TUNING CONTROL OF PROCESSES WITH SIGNAL LEVEL AND RATE CONSTRAINTS

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In the last few years several self-tuning controllers based on minimizing multi-step quadratic criterion functions have been proposed (Clarke and Mohtadi, 1987; Soeterboek et al., 1986). These controllers calculate a controller output sequence over the control horizon which minimizes the criterion. However, signal level constraints and/or rate constraints are not taken into account. In order to calculate an optimal controller output sequence over the control horizon in the presence of the constraints, the constrainted criterion has to be minimized. This minimization can be achieved by using various optimization techniques, e.g. quadratic programming methods or gradient projection methods. Using one of these optimization methods without any modifications yields large calculation times, which are necessary to find the minimum of the criterion with sufficient accuracy. Besides, these calculation times are highly affected by the initial values of the methods.

In this paper a gradient projection method will be presented which is specially adapted to minimize multi-step quadratic criteria in the presence of signal level constraints and rate constraints. This algorithm, called the DGP (Dedicated Gradient Projection) algorithm, uses an approximate solution of the optimization problem as a starting point in order to keep the calculation time small. The approximate solution is calculated by an heuristic algorithm, called ACH (Active Constraint Handling, Soeterboek et al., 1987) which has been modified to find an approximate solution in the presence of rate constraints too. The performances of a process with signal level constraints and rate constraints controlled by the DGP algorithm will be compared to the performances of the process controlled by the MURHAC algorithm. This algorithm, introduced by Lemos and Mosca (1985) and modified by Soeterboek et al. (1986) minimizes the criterion without taking the constraints into account. One of the performance criteria is the calculation time.

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ROBUST OPTIMAL OUTPUT FEEDBACK OF A WIND ENERGY CONVERSION SYSTEM

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Keywords: Wind energy conversion system, modelling and simulation, multi-model robustness, optimal output feedback control, singular value analysis.

The use of wind energy conversion systems for the production of electrical energy reveal several new aspects with respect to the control system design. Major disturbances acting on a wind power plant are wind turbulence and gusts as well as grid voltage fluctuations. These excitations result in strong mechanical forces acting on the primary shaft, gear and on the secondary shaft. The control problem can be stated as finding a control system design with which energy capture and quality of the electrical power are maximized, and with which the mechanical loads are minimized.
The wind turbine under consideration is an horizontal axis turbine with a rated power of 300 kW. The electrical conversion system consists of a synchronous generator with a controlled bridge–rectifier, a dc–current circuit, and an inverter. This conversion system enables the wind turbine to be operated at a variable speed. The system has multiple inputs (blade/pitch angle, generator field voltage, rectifier delay angle), and multiple outputs (speed, power). Between these variables there is a large amount of interaction present. Also, the dynamics of the system contain slow modes (rotor inertia), low–damped torsional modes as well as fast dynamics from the electrical conversion system [1].
The conflicting control requirements make the control problem very suitable for treatment as an optimization problem. A very powerful method is the linear quadratic optimal control method (LQ). In a previously reported study [2] very good results have been obtained with LQ state feedback of the wind turbine. However, in order to design an implementable controller, an output feedback design has to be made. This is possible using observer techniques (c.f. LQG). Nevertheless, due to the high dynamic order of the model and the few number of outputs, this would result in a very complex controller. Another approach is the parametric optimal control or optimal output feedback method [3], with which it is possible to use the controller's internal structure as part of the design process. In this way it is possible to compete with classical PID controllers in the sense of complexity, and to use the feedback structure for loop transfer shaping purposes.
Because the model of the wind turbine contains nonlinearities, the dynamics depend on the operating conditions. To obtain performance robustness for these variations, a multi model synthesis is used with optimal output feedback. In order to quantify the stability robustness for small modelling uncertainties, a singular value analysis is made.
The results for the wind energy conversion system indicate that a very good performance can be realized with respect to energy capture, speed and power fluctuations and mechanical loads, compared to classical siso (PID) systems.

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PARAMETER ESTIMATION IN UNCERTAIN DYNAMIC SYSTEMS FROM SIGNALS WITH BOUNDED NOISE

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Summary

In modelling ill-defined systems lack of knowledge about the measurement error and unavoidable structural error often preclude the use of the ordinary stochastic approach of the parameter estimation problem. As an alternative, the problem can be cast in set-theoretic terms. Here the only assumption is that noise and parameters are bounded. The estimation task is to find a set of parameter vectors in the parameter space that gives rise to acceptable model behaviour in view of the measurement data available. A robust technique of obtaining a sample out of this space uses Monte Carlo simulation. Two problems arise, however, for which solutions are proposed in this presentation. The first is the limited information yield of the procedure for model validity. The second is the computational inefficiency. To solve the first problem, information from min-max estimation is used. The second problem is tackled through a number of supplementary techniques. Initial parameter space dimension reduction is possible by applying analytical techniques, like period-average analysis, using available data. A further improvement of the efficiency is by standardization of the parameters followed by principle component transformations. The latter is particularly useful to reduce the detrimental effect of correlations between parameter estimates. Introduction of the fuzzy set concept into the unknown-but-bounded approach will improve the flexibility and the informative function of the procedure to solve the problems.
The procedure is illustrated by application to an environmental model.

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CONTROL PROBLEMS MOTIVATED BY MOTORWAY TRAFFIC

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SUMMARY

Within the context of inter-urban road-traffic there are several "niches" of which it is recognised that application of techniques from control theory offer potential benefits. We will review some of these.

Those niches appear at various levels. At a basic level the problem of road-section control appears. Here one tries to make the most of existing road capacity by keeping control on traffic flow conditions as speed and volume. This problem will be addressed in more detail in the last paper of this section (Smulders). The next level is the level of the network. Here also some interesting control problems appear. Based on momentary or forcasted traffic conditions, rerouting and driver-information schemes are envisioned to make better use of the network structure. Finally the possibility of "road-pricing" is discussed for which there now is a proposal to introduce it in the Netherlands by the mid-nineties. Here control and optimisation is not exercised by traffic measures as such, but by influencing the demand side instead. The optimisation problem then turns more into an economic one.
Viewing these problems in the level-perspective shows their relative independence in the sense that solving a problem at one level does not interfere with the necessity of activities at the other levels.

Finally, with a few examples it will be stressed that to come to fruitful applications in the traffic area, one should really appreciate the peculiarities of road traffic at the moment traffic behaviour is catched in "system-equations" to mould it into the framework of control theory. It is not a passive medium one has to do with, but it is both active and intelligent instead, sometimes leading to unexpected reactions.

The regular free-endpoint LQ-problem with indefinite cost

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In this talk we are concerned with regular, infinite horizon linear quadratic optimal control problems in which the cost functional is the integral of an *indefinite* quadratic form.

In most of the existing literature on the regular linear quadratic problem or LQ-problem, it is explicitely assumed that the quadratic form in the cost functional, apart from being positive definite in the control variable alone, is positive semi-definite in the control and state variables simultaneously. In fact, under this semi-definiteness assumption the LQ-problem has become quite standard and is treated in many basic textbooks in the field of systems and control. Often, a distinction is made between two versions of the problem, the *fixed-endpoint* version and the *free-endpoint* version. In the fixed-endpoint version it is required to minimize the cost functional under the constraint that the optimal state trajectory should converge to zero as time tends to infinity, while in the free-endpoint version it is only required to minimize the cost functional. For the case that the quadratic form in the cost functional is positive semi-definite both versions of the regular LQ-problem are well-understood and completely satisfactory solutions of these problems are available.

Surprisingly however, for the most general formulation of the regular LQ-problem, that is, the case that the quadratic form in the cost functional is indefinite, a satisfactory treatment not yet exists. In this case we can again distinguish between the fixed-endpoint version and the free-endpoint version. While for the fixed-endpoint version a complete solution has been described in [1], the free-endpoint version has only been considered in [1] under a very restrictive assumption. Thus we see that, up to now, the free-endpoint regular LQ-problem with indefinite cost functional has been an open problem. In [2] we filled up this gap and presented a fairly complete solution to this problem.

It is well-known that for the free-endpoint regular LQ-problem with positive semi-definite cost functional the optimal cost is given by the smallest positive semi-definite real symmetric solution of the algebraic Riccati-equation. We will see that this statement is no longer valid in general if the cost functional is the integral of an indefinite quadratic form. It will be shown however that also in this case the optimal cost is given by a solution of the algebraic Riccati-equation. This particular solution will be characterized in terms of the geometry on the set of all real symmetric solutions of the algebraic Riccati-equation as described in [1] and [3].

Another well-known fact is that for the free-endpoint regular LQ-problem with positive semi-definite cost functional the *existence* of optimal controls is never an issue: under the assumption that the underlying system is controllable, for this problem always unique optimal controls exist for all initial conditions. This is in contrast with the fixed-endpoint LQ-problem, where the existence of optimal controls for all initial conditions depends on the "gap" of the algebraic Riccati-equation (i.e. the difference between the largest and smallest solution of the Riccati-equation). In this talk we will see that also for the free-endpoint regular LQ-problem with *indefinite* cost functional no longer optimal controls need to exist for all initial conditions! Moreover, we will establish a necessary and sufficient condition in terms of the "gap" of the algebraic Riccati-equation for the existence of optimal controls for all initial conditions. We will show that for the particular case that the cost functional is positive semi-definite this condition is always satisfied, thus explaining the fact that in this special case optimal controls always exist. Finally, we will show that also in the indefinite case the optimal controls for the free-endpoint regular LQ-problem, if they exist, are given by a feedback control law.

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OPTIMIZATION OF HEAT DELIVERY TO APARTMENT BUILDINGS USING AN IMPROVED BUILDING MODEL

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ABSTRACT

Difficulties with the actual operation of district heating systems made it necessary to investigate and reconsider the problem of heat delivery. In Utrecht, PEGUS (Provinciaal en Gemeentelijk Utrechts Stroomleveringsbedrijf) operates some 100 apartment buildings (about 10000 apartments). The thermal power (primary energy) is mainly provided by the Combined Heat and Power Station (C.H.P.) in Utrecht.

There is a deep believe that by lowering the installation water temperature during the night stand-by the heating costs can be reduced. However, during the morning peak hours secondary heat sources have to be put into operation to satisfy the increases in thermostat set points. This makes the reheating process much more expensive. In extreme cases it can happen that the total energy cost even becomes higher than that of keeping the installation temperature constant during the night.

The aim of this paper is to provide an optimal control strategy minimizing the total energy cost meanwhile satisfying some temperature requirements in the building. In our process model special attention was paid to the wall dynamics. Many building models available in the literature [1] use a lumped approach of the walls leading to an inaccurate high-frequency behaviour (the Bode-diagram of a lumped wall model goes to the asymptotic value of -20 dB/dec. instead of the precise value of -10 dB/dec.). To improve the high-frequency dynamics of our model the walls (which may have several layers) were taken into account as distributed parameter systems. Their distributed transfer functions were determined by solving the coupled KIRCHHOFF-FOURIER heat conduction equations for various initial- and boundary conditions using a general matrix method. The precise solution is rather complicated but can be approximated by a low-order lumped model with good accuracy for low- and high frequencies. Additionally it provides information about the indoor wall surface temperature enabling estimation the heat losses through the walls. Real-time measurements from an apartment building in Utrecht showed good matching with our process model [2].

Using dynamic optimization it was possible to elaborate control policies reducing the energy consumption (and cost) and shaving the morning power peak. 4 different control strategies were tested and compared. We plan to test the optimal heat delivery strategy in real-time during the current heating season.

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Data-assimilation in wave prediction models.

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Abstract.

Spectra of sea-surface waves are currently predicted in real-time using a numerical model for the generation and propagation of wind induced waves. Comparing these predictions with observations (buoy- and satellite measurements), frequently substantial deviations are found, which are mainly attributed to errors in the forecasted wind fields that are fed into the wave model. This leads to the idea of using observations to improve the estimate of the present sea state ("data-assimilation" in oceanography and meteorology); in particular, a better initial condition for a subsequent forecast run of the model can be obtained in this way. Presently, Delft Hydraulics participates in a research project aimed at development of a data-assimilation algoritm for a regional wave prediction model, and evaluation of the effect of of satellite data on wave prediction.

Approach of the problem: assuming that the wave model is perfect, an estimate $x(n)$ of the state of the wave model consisting of discretized wave spectra at the gridpoints at an instant n is given by $x(k+1)=F(x(k),\alpha)$; $k=m,..,n-1$ with F representing the wave model, α an uncertain vector representing all wind fields over $\{m,..,n\}$, and $x(m)$ an initial condition. The problem is now formulated as the following optimal control problem: find a vector of wind-fields α that minimizes some least-squares type functional assigning costs to deviations of estimated wind fields from forecasted wind fields and deviations between wave observations and corresponding estimates. The complexity of the wave model has forced us to use an approximate model for data-assimilation; even then, the very large dimension of the state vector and in general poor controllability of the tangent system do not allow use of an extended Kalman filter to solve the problem approximately. An iterative algoritm is now being developed based on a gradient method for minimization of the cost functional; still problems resulting from system structure and dimension of α are expected.

Newton Methods for Structured Parametric LQ Problems

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This paper considers the design of control systems with a predefined feedback structure, where the free parameters are chosen optimal with respect to a quadratic performance criterion.
Examples include static or dynamic output feedback and optimal decentralized feedback control.
For this class of SPLQ-problems the paper presents an analytic formulation of Newton algorithms that is shown to have favorable properties with respect to convergence and efficiency. The paper discusses the proposed algorithm, the numerical computer implementation and shows a comparison with known quasi-Newton methods.

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State feedback traffic control of the transient behaviour of underground public transportation systems

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Abstract

The paper proposes two methods of traffic regulation of public transportation systems during transients, for example during the modification of the intervals between the trains.
Both methods are based on optimal control theory for linear systems with quadratic criterion. In the first approach the system is controlled with respect to a new nominal time schedule to be generated accordingly to the new situation while the second method realizes interval control without reference to a nominal schedule.
The properties of both methods are analyzed and simulation results are discussed and compared.

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CRITERION BASED MODEL EQUIVALENCE IN MULTIVARIABLE SYSTEM IDENTIFICATION

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Abstract

The problem of system identification is considered in terms of (approximate) modelling of a given sequence of measurement data. Given a data sequence of a multivariable process, there are two aspects that play a central role in determining the properties of the identified models: the set of models $\mathcal{M}$ that is taken into account, and the identification criterion that selects the identified models from this set. When parametrizing a set of models $\mathcal{M}$ very often use is made of a notion of model equivalence in order to arrive at a uniquely identifiable model set $\mathcal{M}^* \subset \mathcal{M}$, such that $\mathcal{M}^*$ contains equivalent models to all models within $\mathcal{M}$. The applied model equivalence conventionally refers to input–output properties of the model. For this situation it will be shown that the dynamical properties of identified models might be dependent on the specific choice of model set $\mathcal{M}^*$, i.e. the specific parametrization chosen, leading to identified models that – to some extent – are arbitrary. This is caused by the fact that the equivalence relation between models is not necessarily in accordance with the identification criterion. Consequently a criterion based notion of model equivalence will be introduced and specified for several identification criteria. For equation error identification methods the "overlapping" parametrization will be shown to constitute a set of canonical forms with respect to this criterion based model equivalence.

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Design of optimal input signals with very low crest factor

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This work is supported by the National Fund for Scientific Rersearch

Abstract

The estimation of the parameters of a model of a Device Under Test (D.U.T.) requires the measurement of both an input test signal, applied to the D.U.T., and the output of the D.U.T. with a digitizer. To minimize the covariance matrix of the parameters to its Cramer-Rao lower bound, a Maximum Likelihood Estimator (M.L.E.) can be used. This Cramer-Rao lower bound, being the inverse of the Fisher information matrix, can further be minimized by taking into accound the spectrum of the input signal [1]. It can be shown that an optimal design can be obtained by appropriately choosing the magnitudes and frequencies of a multisine, a discrete sum of sines. The frequencies of the multisine are positioned as to maximally excite the D.U.T. in all of its interesting modes. The square of the magnitudes corresponds to the relative amount of energy injected in that particular part of the D.U.T.'s spectrum. The phases of the multisine do not interfere with the spectral energy considerations and can, according to this frequency domain optimization theory, arbitrarely be chosen.

Another aspect to input signal optimization is the time domain crest factor reduction [2]. This consists of choosing the phases of the input signal in such a way that both the input and output signal are maximally compressed. This has the enormous advantage of one being able to inject a maximum of energy in the D.U.T. without any fear for signal clipping or any other unwanted non-linear distorsion effect. Even more important is the fact that compressed signals can be read with a digitizer with a minimum of quantization noise because these signals spend most of their time at their tops. The maximum energy injection and the low quantization noise result in a significantly higher signal-to-noise ratio (S/N R) than would otherwise be the case.

Up until now the time domain compression had not been incorporated in the Fisher information matrix although it has a manifest impact on the covariance matrix. In this lecture a unification of time and frequency domain optimization of input signals is presented.

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A least squares parameter estimation method for some uncommon models

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Abstract

Using a Q-R decomposition of a certain matrix, an efficient algorithm arises for computing least squares estimates for the unknown parameters of an ARMA-model from noisy measurements of inputs and outputs (cf. [2], [3]). The corresponding estimators are consistent and asymptotically normal under some conditions (cf. [1], [3]).

This presentation deals with two generalizations of the estimation problem described above:

1. Constraints on the parameters
2. Partial input noise.

For these probems, least squares estimates can still be computed efficiently by performing Q-R decompositions. Assuming now some obvious extensions of the conditions, consistency and asymptotic normality are obtained again.

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Title

Optimal Control of a Processor Sharing Queueing System.

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Abstract

The operational units in the telephone network are the so-called telephone-switches or -exchanges. The exchanges of the *Stored Program Controlled (SPC)* type are basically computers that are designed for performing the special tasks associated with the maintenance of telephone traffic. An SPC-exchange in operation is thus a typical example of a queueing system where customers compete for a number of limited resources. These limitations stem from both the finite processor capacity and the limited number of hardware resources in the exchange. Without any form of overload control the performance of an SPC-exchange may therefore degrade significantly during periods in which the demands for service exceed the design capacity. We will present a queueing model for an SPC-exchange, consisting of a *Processor Sharing* queue, and show how the behaviour during overload can be improved by controlling the rate at which jobs are admitted to the exchange.

Abstract

SOME REMARKS ON DISTURBANCE DECOUPLING WITH STABILITY
FOR NONLINEAR SYSTEMS

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A well-known synthesis problem in systems theory is the Disturbance Decoupling Problem with Stability (DDPS). This problem is completely solved for linear systems (see [4]). For nonlinear systems however, the solution of DDPS is unknown, although the Disturbance Decoupling Problem is (locally) solved (see [1]). In this talk we will consider the DDPS for a special class of nonlinear systems, viz. the class of feedback linearizable systems with nonlinear outputs. We will show that the DDPS is (globally) solvable by applying a linear feedback if and only if the DDPS for an "associated" linear system is solvable. As application we consider a 3-degree of freedom robot manipulator.

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Summary of a paper submitted for the 7th Benelux Meeting on Systems and Control, March 2-4, 1988, at Heijen.

MODEL OF THE HUMAN OBSERVER AND CONTROLLER OF A DYNAMIC SYSTEM - Theory and Validation -

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This paper deals with a model of the human controller of a dynamic system involving not only (short term, continuous closed loop) regulating, but also (often long term, intermittent, open loop) tracking a desired finite trajectory in some optimal sense. The latter concerns control behavior at a higher mental level involving planning (pre-programmed open loop control) and decision making (to determine sequentially whether or not such a maneuver has to be initiated and/or stopped).

The model, which will be indicated in the following with MMS (Man-Machine-System) model, describes the complex visual information process (including an optimal scanning strategy) and the control and decision making behavior in terms of stochastic optimal estimation, control and decision theory, providing an integrated framework of all important and interrelated aspects of the aforementioned human control task.

The task considered is to control a dynamic system from state A to state B with a given desired course, without prior knowledge about this course but based on perceived information about the present state and the future desired state from instruments and/or the outside world. The various aspects of the task are: the task definition (minimization of a quadratic, finite time, cost functional), the linearized, time-varying dynamic system, the environment and human control behavior. The latter comprises: visual perception and state estimation, continuous regulating against random disturbances and intermittent maneuvering: once a systematic deviation of the given state reference is detected, the human operator (HO) generates an open loop control sequence to track the desired trajectory and a closed loop control strategy to compensate for random disturbances.

Model outputs are in terms of the means and covariances of all (normal distributed) task variables of interest with time, providing all statistical information of the task performance. In addition, a submodel describes how the HO derives optimally the information from the visual scene and the instruments rendering a useful insight in display related questions. Also HO workload is predicted by a submodel involving the psychological notions attention and arousal.

In the paper the MMS model is applied to the manual control of a ship. The specific example is the task of entering a harbor utilizing the visual scene information provided by buoys, the geometry of the harbor entrance and the terminal situation. Model results are compared with experimental results of a simulator program showing the predictive capability and validity of the MMS model.

It is anticipated that the MMS model is sufficiently general to be useful to investigate a variety of man-machine-systems, e.g. in the increasingly important area of robotics and in the handling of ships and helicopters.

Design of an H_∞ controller for an inverted double pendulum system via a polynomial approach

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When developing a control system design methodology it is normally desirable to study its practical implementation on specific real systems. Such case studies are not only proving grounds. They provide useful feedback concerning practical difficulties and may also yield some insight into the theory. The design methodology considered here is the polynomial approach of Kwakernaak to the "mixed sensitivity" H_∞ control problem [1]. The chosen example is that of an inverted dubble pendulum system, which is considered to be particularly difficult to control [2]. Our aim is to design a robust linear controller for the system via the polynomial approach to the H_∞ control problem coupled with the most recently available software for its numerical solution [3].

After a brief outline of the motivation, formulation and numerical solution of the H_∞ control problem, the particular difficulties presented by the pendulum system are discussed, principally with regard to its non-linearity, non-squareness, instability and non-minimum phasedness. Finally the design of a practical H_∞ robust controller via the polynomial approach will be discussed. Particular attention is given to the rational choice of weighting functions which arise in the theory.

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The use of recursive identification techniques with regard to thermal modelling of buildings and test-cells

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The use of detailed thermal models for predicting the thermal behaviour of buildings becomes rather common (e.g. ESP, LPB1, TRANSYS, ..).
However, the techniques for predicting the thermal properties of buildings form the analysis of their thermal behaviour (= model identification) are still on research level.
One of the major topics within the CEC's Passys (1985-1988) project is the development of techniques which allows the determination of the thermal performance of large test cells.
The presentation will show some of the recursive identification model which can be used for real buildings and test cells as well as results obtained from measurements.

A RELATION BETWEEN THE COPRIME FRACTIONS AND THE GAP METRIC AND ITS APPLICATION TO ROBUST STABILIZATION

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Abstract

Assume P_i (i=1,2) are transfer matrices and P_1 has a right coprime fraction (r.c.f.) pair (N_1, D_1) i.e.

i) D_1 is invertible ;
ii) there exist X and Y such that $XN_1 + YD_1 = I$;
iii) $P_1 = N_1 D_1^{-1}$.

Denote by $\Pi(P_i)$ (i=1,2) the projection to the graph of P_i (P_i can be interpreted as a closed operator mapping input space to output space).

Define

$$\begin{bmatrix} D_2 \\ N_2 \end{bmatrix} := \Pi(P_2) \begin{bmatrix} D_1 \\ N_1 \end{bmatrix} .$$

We have proved that $(N_2\ D_2)$ is a r.c.f. pair of P_2 if and only if

$$\delta(P_1, P_2) < 1$$

where

$$\delta(P_1, P_2) := \| \Pi(P_1) - \Pi(P_2) \|$$

is the gap between P_1 and P_2 .

By using this result, we obtained some sufficient conditions for robust stabilization. These conditions allow the system and compensator to be disturbed simultaneously.

References:

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AN UPPER BOUND OF THE IDENTIFICATION ERRORS OF MIMO LINEAR PROCESSES

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Abstract

This work attempts to solve the following problem: Derive a suitable description of the modelling errors (model uncertainty) of MIMO transfer function models which are obtained by black-box identification; this description must supply the quantitative information required for robustness study of the feedback system where the black-box model is used for the controller design.
An upper bound of modelling errors will be estimated. We shall refer to the asymptotic theory on the properties of black-box transfer function estimates, developed recently by Ljung and Yuan. Their theory shows that the transfer function estimates are consistent, the errors of the estimates are asymptotically joint normal, with a very simple expression for their covariances. In this work, their results will be extended to cases where spectral analysis is used. Based on this theory, a bound of modelling errors is defined as the sum of the absolute value of the bias part and the 3σ bound of the variance (random) part of the modelling errors. Algorithms are proposed for the computations. The criteria for robustness analysis of feedback systems, making use of the upper bound derived here, will be given as well.

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STABILIZABILITY FOR INFINITE DIMENSIONAL LINEAR SYSTEMS

by

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In this lecture we shall discuss the stabilizability of the following linear time invariant system.

(1) $$\dot{x}(t) = Ax(t) + bu(t);\ x(0) = x_0$$

where A is an infinitesimal generator of the semigroup $T(t)$ on the state space $\mathcal{X}$, $\mathcal{X}$ is a general Banach space, b is an element of $\mathcal{X}$ and $u(.):[0,\infty)\mapsto\mathbb{R}$ is the control action.

For this system we shall introduce the concept of open loop stabilizability i.e. for all $x_0 \in \mathcal{X}$ there exists an input $u(t)$ such that the solution of (1) has exponential decay, and we shall prove that this property imposes restrictions on the spectrum of A.

Furthermore we shall discuss the relation between open loop stabilizability and the existence of a bounded feedback law F such that the closed loop system

(2) $$\dot{x}(t) = (A + bF)x(t)$$

is exponentially stable.

Some related references are:

C.A. JACOBSON and C.N. NETT; Linear State–Space Systems in Infinite Dimensional Space: The Role and Characterization of joint Stabilizable/ Detectability, to appear in IEEE

S.A. NEFEDOV and F.A. SHOLOKHOVISCH; A Criterium for the Stabilizability of Dynamical Systems with Finite Dimensional Input, Differentsial'nye Uraveneniya, Vol. 22, 1986, pp. 163–166, New York, Plenum.